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Revegetation Augmentation of Surface Mines With Treated Acid Mine Drainage

Interagency Energy/Environment R&D Program Report

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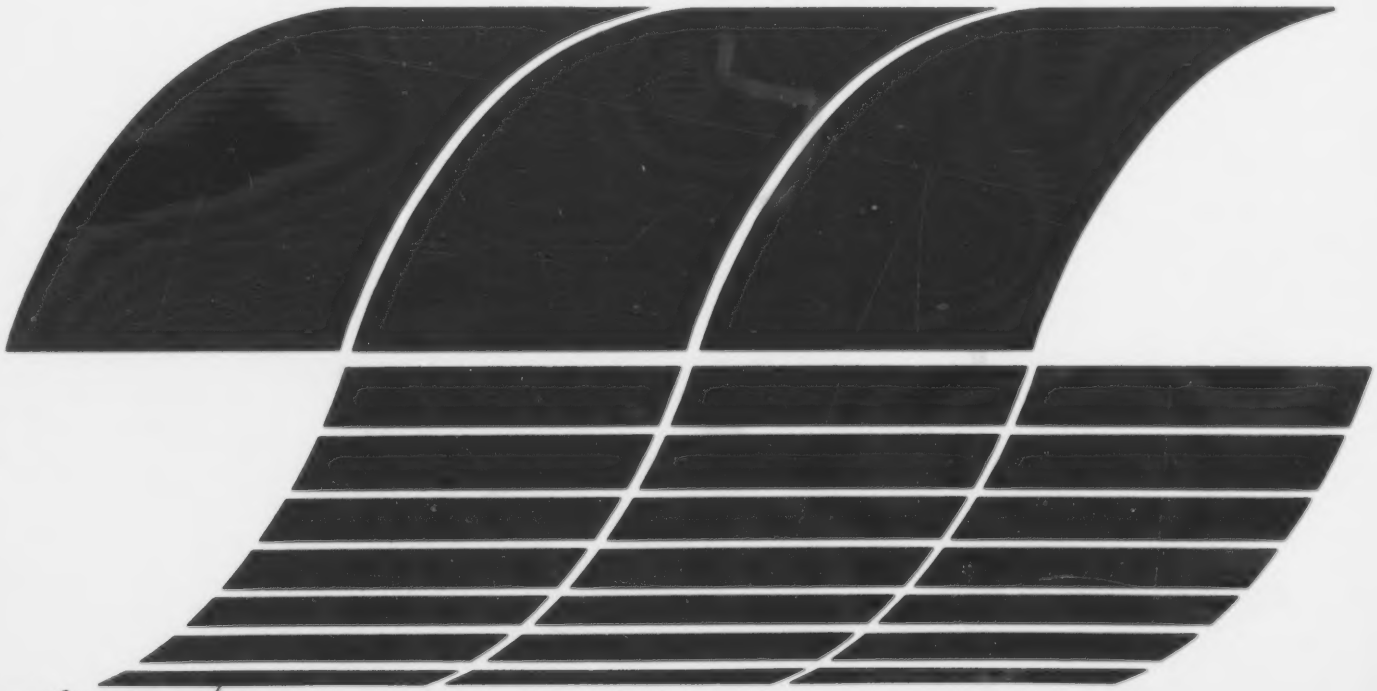

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March 1980

REVEGETATION AUGMENTATION OF SURFACE MINES WITH TREATED ACID MINE DRAINAGE

by

Wayne A. Rosso
S.M.R. Engineering and Environmental Services
Central City, Kentucky 42330

Grant No. 14010 HNS

Project Officer

Ronald D. Hill
Resource Extraction and Handling Division
Industrial Environmental Research Laboratory
Cincinnati, Ohio 45268

This study was conducted in
Cooperation with the
Kentucky Department for Natural Resources
and Environmental Protection
and the Peabody Coal Company
Central City, Kentucky 42330

INDUSTRIAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

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FOREWORD

When energy and material resources are extracted, processed, converted, and used, the pollutional impact on our environment and even on our health often requires that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory - Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

A common problem of treatment of acid mine drainage is the disposal of sludges produced by chemical treatment of the water. This study was conducted to evaluate and test a system utilizing treated acid mine drainage as irrigation water. This system would have the advantage of disposal of sludge as well as providing often needed irrigation water. The report should be of interest to state, federal or private companies involved with the treatment of acid mine drainage and disposal of by-product sludges. For further information contact the Resource Extraction and Handling Division of IERL-Ci.

David G. Stephan
Director
Industrial Environmental Research Laboratory
Cincinnati

ABSTRACT

This study provided a field demonstration of an earlier feasibility study. Treated acid mine drainage was utilized to augment revegetation on graded spoil areas. Acid mine drainage was treated utilizing limestone (rock dust) and the resultant water was spray irrigated under high pressure onto the plots. Three treatment and a control were used to evaluate the effects of the irrigation on the vegetation and resulting surface runoff. The three treatments applied via irrigation were raw acidic water, treated water with sludge and treated water without sludge.

All three treatments enhanced vegetation response in varying degrees when compared to the control plot. Irrigation of treated water with sludge deposited some of the sludge (treatment by-products, unreacted limestone and ferric hydroxide) onto the plots. When irrigation was applied at a rate of 2.5 cm/4 hours, approximately 30 percent of the water was recovered as surface runoff.

No detrimental water quality impact was noted by the deposition of treatment sludge onto the plots. Runoff from natural precipitation events produced runoff water of similar quality to control areas.

This report was submitted in fulfillment of Project 14010 HNS by the Kentucky Department for Natural Resources and Environmental Protection under the sponsorship of the U.S. Environmental Protection Agency. Work was completed as of December 1979.

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SECTION 1

INTRODUCTION

Where acid mine drainage (AMD) is encountered during the surface mining of coal, the water must be treated to meet specific discharge limits for pH, iron, manganese, and suspended solids. The acid water is usually neutralized with lime, limestone, sodium hydroxide, or another alkaline material. This process is followed by the removal of the iron hydroxide, calcium sulfate, etc. by settling and the discharge of the treated water to a receiving stream. The sludge produced by the treatment process is difficult to separate from the water and presents disposal problems. In addition, the surface mining process is a dynamic one, with extraction, grading, and reclamation occurring over a short period of time. Thus, the treatment system must be moved frequently.

Following the extraction of coal and grading of the overburden, the mined area is usually seeded with grasses, legumes, and sometimes trees. One cause of vegetation failure is the lack of moisture during the dry summer months. Irrigation during these critical times would greatly assist the establishment of a vegetative cover. One solution to this problem would be the use of treated acid mine drainage as irrigation water. This H_2O is near the areas being reclaimed, and pumping and piping costs could be minimized. In addition, the treated water could be placed to a beneficial use, and in some cases, the discharge to a stream could be eliminated. The sludge removal, handling, and disposal problem could also be eliminated if the sludge were not separated from the treated water, but sprayed along with it. The excess alkalinity in the sludge and water might also be beneficial to the soil.

The U.S. Environmental Protection Agency (EPA), in a joint program with the Kentucky Department for Natural Resources and Environmental Protection, contracted for a study to determine the feasibility of this concept. The findings of this study were published in 1972 in the report Revegetation Augmentation by Reuse of Treated Active Surface Mine Drainage, (Zaval, 1972), which concluded that the concept was feasible. The Commonwealth of Kentucky then contracted with the Peabody Coal Company to carry out a demonstration. The test program was carried out in four phases:

1. Preplanning, site preparation, and equipment procurement

(1976).

2. Irrigation studies under four different treatments (1977):
   A. Irrigation with treated AMD containing sludge.
   B. Irrigation with treated AMD with sludge removed.
   C. Irrigation with untreated (raw) AMD.
   D. No irrigation.
3. Testing of irrigation with treated AMD containing sludge at different irrigation rates (1978).
4. Data analysis and report preparation (1979).

SECTION 2

CONCLUSIONS

1. This study showed that it is feasible to use neutralized AMD for irrigation of vegetation on reclaimed spoils.

2. Application of limestone-neutralized AMD water onto experimental plots enhances ground cover and harvest weight over control areas.

3. No significant difference was noted between treated water with sludge and treated water without sludge with respect to ground cover and harvest yields.

4. The mobile, once through limestone system used produced sufficient neutralization to meet effluent limits.

5. Runoff from irrigation at the application rates used will not meet EPA effluent criteria for iron, manganese, or suspended solids.

6. When raw water contains small amounts of acidity, it may be possible to produce neutralized water by irrigation of spoil containing large amounts of limestone.

SECTION 3

RECOMMENDATIONS

1. Irrigation of mine spoil with limestone-treated water should be viewed as a viable option, especially in areas already needing water treatment. The irrigation can:
   A. Expand planting season.
   B. Permit easy application of nutrients via the irrigation system.

2. The feasibility of irrigating raw acidic water onto heavily limed and vegetated spoil should be fully explored. The following questions must be answered:
   A. At what application rates and drying periods will neutralization be effective?
   B. Will neutralization be effective at only moderate (100-400 mg/l) acidity values?
   C. If limestone beds have to be periodically relimed, what rate and frequency should be used?

3. The irrigation system should be designed to minimize runoff.

4. Silt basins or other facilities for removal of suspended solids and precipitated metals should be located below any large irrigation project.

5. Raw water pumps should be made of stainless steel or other acid-resistant materials.

SECTION 4

PROCEDURES

The project extended from earth moving in April 1976 until final field work was completed in the fall 1978. The ground work was finished in July 1976. During 1976, the experimental plots were established, the treatment system was installed, and the monitoring systems tested. The plots were seeded, fertilized, and limed as soon as final grading of the spoil was completed. All seeded species germinated, however optimum germination and survival did not occur, as seeding was completed a month after the recommended period. Research completed in 1977 was primarily devoted to field testing and data gathering on the three separate treatments. At the completion of the 1977 field work, it was decided the only practical method for a mining operation would be the irrigation of the treated water with its sludge. In addition, it was believed that information was needed to define:

1. Runoff variation resulting from differences in irrigation intensity.

2. The effects of continued, heavy saturation irrigation on suspended solids and metals.

3. The fate of irrigation water (evaporation, runoff, and infiltration) at different application rates.

NEUTRALIZATION SYSTEM

Water Source

The source of water for the experimental project was a 400-m (1500-ft) long surface mine pit. This pit was narrow and contained approximately 19 million liters (5 million gal) of acid water. It provided a sufficient water source for irrigation. Since the lake was lower in elevation than the plots to be irrigated, a storage lagoon was designed near the plots to provide a constant supply of water during irrigation. A raw water pump was installed adjacent to the water pit. This 10-cm (4 in.) centrifugal pump supplied water to a 30-m by 20-m and 3-m deep raw water lagoon. The lagoon was designed to hold 1,325,000 liters (350,000 gal) and served as a holding basin for the water supply. Because of the porosity of the spoil, the

lagoon was lined with bentonite.

Liming System

The neutralization system used in this project was a specially designed electric mixmeter built by Heyl-Patterson. This machine was designed to batch mix 1150 liters of limestone slurry and meter the material to a 10-cm (4-in.) electric pump. This treated water would then either go to a settling lagoon for clarifying or directly to the irrigation pump (Figure 1). This lagoon also required lining with bentonite to minimize leakage.

Irrigation Equipment

The irrigation system chosen for this project was a high pressure nozzle system recommended in an earlier study (Zaval, 1972). The system consisted of a solid set arrangement with Rain Bird 104C full circle rain guns. Ten-cm (4-in.) aluminum quick connect pipe was used to supply irrgation water to the center of the plots. The rate of application of irrigation water could be varied from 360 to 567 liters/minute (95 to 150 gallons per minute (GPM). One irrigation gun per plot was used and mounted on a 1¼ m riser located in the center of the plots (Figure 1).

Operator Procedure

All labor requirements were performed by local members of United Mine Workers of America. Generally two laborers were needed for every irrigation run. Supervision was provided by project staff. When an irrigation run was scheduled the raw water pump was started the previous afternoon. This would insure a full raw water lagoon for the next day's irrigation activities.

Irrigation - Raw Water

When the irrigation schedule called for irrigating the raw water plot, water was obtained from the raw water lagoon. Raw water was provided to the irrigation pump via a gravity flow pipe and valve (Figure 1).

Irrigation - Treated Water With Sludge

The limer was charged with 455 kilograms (kg, 1000 lb) of rock dust and 1150 liters of water. This mixture was allowed to agitate for 15 minutes or until a uniform consistency was achieved. The slurry was then metered to the suction intake of a 10-cm electric centrifugal pump. Limestone slurry was fed at a rate to achieve a pH of 6.0-6.2 of irrigation water. Raw water was withdrawn from the lagoon by the suction line of the 10-cm pump. This water plus the accompanying slurry was pumped to the irrigation pump and then distributed to Plot 1 (Figure 1).

Irrigation - Treated Water Without Sludge

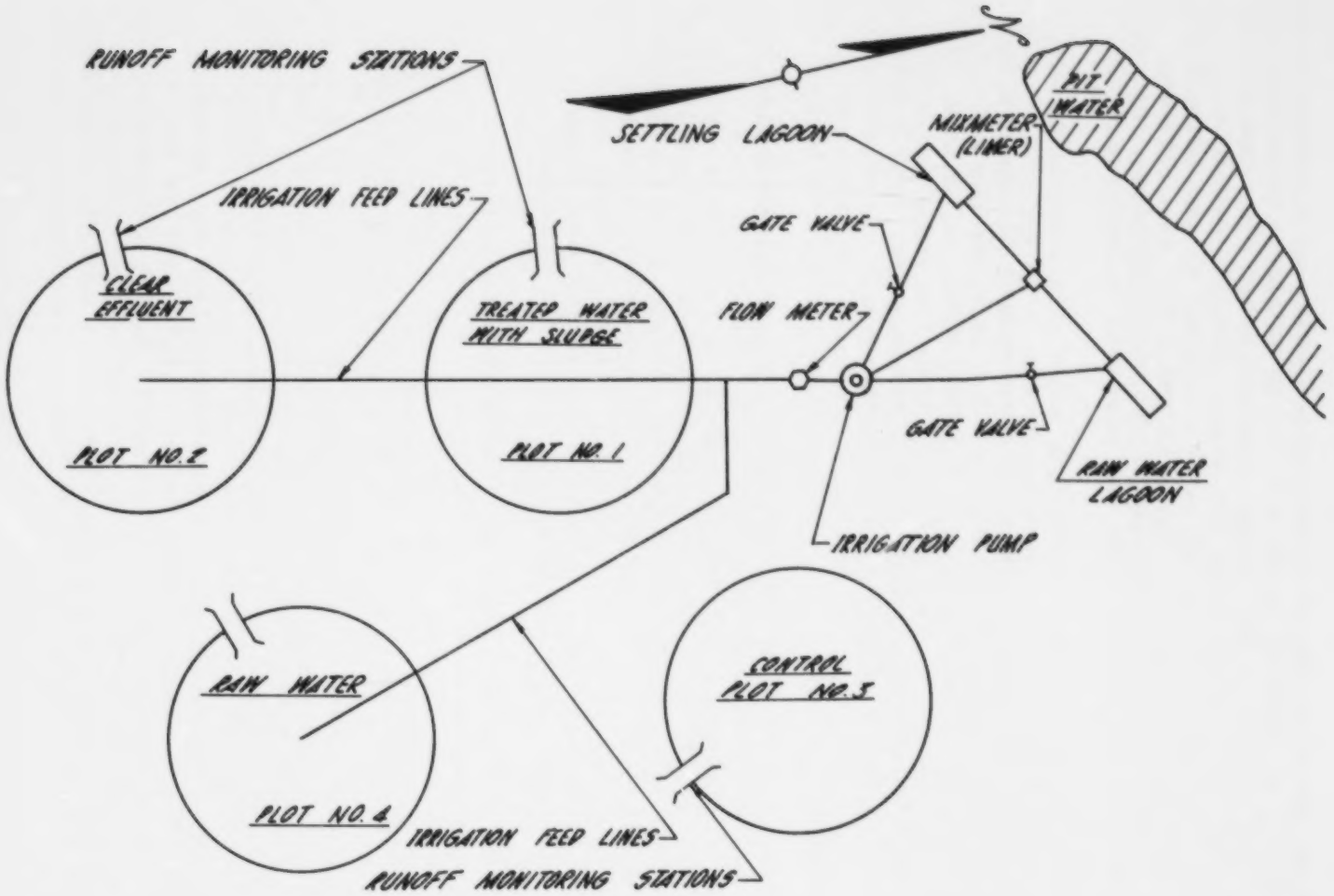

Figure 1. On-site configuration of irrigation scheme for the Vogue-EPA Project, Muhlenberg County, Kentucky.

This system operated the same as treated water plus sludge with the exception of treated water and its by-products went into a treated water lagoon. Sufficient treated water plus its by-products were discharged into the lagoon the day previous to irrigation of treated clear effluent in order to provide a full run of treated clear water. This allowed for a 16 - 24 hour settling interval. After settling, the clear treated water was supplied to the irrigation pump via pipe and valve system.

FIELD PLOTS

The plots were circular in shape to accommodate the Rain Bird full circle rain guns. Plots were 49.2 m in diameter and contained .7 hectares (ha) per plot. All plots had a 1-m high berm that insured collection of all runoff from the plots. Plots were graded with motor scrapers and track dozers. Spoil material was graded in such a manner as to achieve a 1 to 2 percent slope.

Soil Amendments

After ground preparation was completed, all plots were limed, fertilized, and seeded during July 1976. All plots received the same rate of limestone (78 metric tons/ha), fertilizer (93 kg nitrogen/ha; 227 kg P_2O_5/ha; and 135 kg K_2O/ha) and seed (split plots; 1, Kentucky 31 fescue 34 kg/ha; buffalo alfalfa 17 kg/ha; 2, bermuda grass 22 kg/ha and yellow blossum sweet clover 17 kg/ha). In the spring of 1977 and 1978 all plots were topdressed with 34 kg/ha (30 lb/ac) of nitrogen as ammonium nitrate. This has been Peabody Coal Company's standard reclamation practice with this type of spoil. No additional seeding other than the initial planting was provided.

Vegetation

Randomly chosen transects of 30.47 m (100 ft) were established in each plot. Percent cover was then determined by observation of plant cover at each .3 m (1 ft) interval. One hundred points were tallied per transect and percent cover was then tallied. Percent cover was also determined by use of 2.5 cm = 30.5 m (1" = 100') color aerial photographs. These photos were obtained on two separate dates and percent observable cover tallied. Harvest yields were obtained from six randomly chosen one-half m areas in each plot. The vegetation was harvested by clipping. Fresh plant weights were determined and subsamples taken to obtain moisture values. Moisture lost was determined after drying samples at 70° C. Yields were then calculated for the plots and subplots.

SOIL SAMPLING AND ANALYSIS

Spoil samples were collected in several series in order to document any major changes due to irrigation. Initially, the plots

were sectioned into eight quadrants. This was to determine if significant differences existed within and between plots. After spoil amendments the plots were again sampled using two composite samples. In addition to the above surface samples, 10 cm , pits were dug to obtain samples at depths of 0-2.5 cm, 20.3 cm, 45.7 cm, and 91.4 cm. Two sets of samples were obtained; one before any spoil amendments or irrigation and the other after irrigation in 1976 and 1978.

Soil samples were air dried and ground to pass through a 2-mm screen. Samples pH's were determined electrometrically using a water suspension with a ratio of 1:1. Test for available phosphorus was an adaptation of a Bray-1 method (Bray and Kurtz, 1945). Potassium, calcium and magnesium values were determined by analyzing leachate obtained using 1N neutral NH_4OAc. Total potential acidities were performed by University of Kentucky Extension Service using a hydrogen peroxide oxidation method. All procedures were used and approved by University of Kentucky Division of Regulatory Services.

WATER SAMPLING AND ANALYSIS

In June 1976 monitoring and treatment equipment were field tested and readied for operation. Irrigation and testing continued into the fall season until freezing started. Water quality was monitored using Stevens Model 61R flowmeters and ISCO Model 1680 sequential water samplers. Water samples from the mixmeter discharge were composited over the day's run. Run-off from plots was monitored by sequential grab samples.

Routine water analysis completed on runoff water included pH, acidity, and alkalinity. Values for pH's were determined using a combination glass electrode method. Acidity was determined as recommended for mine wastes as according to the 13 th Edition of Standard Methods to an end point of pH 8.3.

Determination of metal values such as total iron, manganese, aluminum, nickel, zinc and other metals was determined on acidified samples after soft digestion. The sample values were then determined using a double beam atomic absorption unit.

Total suspended solids (TSS) values were obtained by filtering a 50 or 100 milliter (ml) sample through glass fiber filters (Gelman Type A-E). The filters were dried and weighed to the nearest 0.01 milligram (mg). Total dissolved solids (TDS) were determined using the filtrate from TSS and evaporating this in a pre-weighed porcelain dish.

The amount of water irrigated onto the plots was determined by a 10 cm Rockwell Turbine in line water meter. Runoff from plots was measured by Stevens Model 61R stage recorder with a 60° steel weir. Small flows were determined by bucket and stop watch method.

SECTION 5

RESULTS

SPOIL CHEMICAL DATA

Pretreatment Spoil Chemistry

The experimental area, before spoil amendments, reflected a harsh environment for plant growth. Spoil chemical data indicated the spoils were extremely acidic (pH 2.7 - 4.9) and low in phosphorus and potassium levels (Tables 1, 2, 3 and 4). The type of spoil chemical conditions present were not unusual for the type of overburden encountered and the stripping methods employed.

Post Amendments

Agricultural limestone was applied at a rate of 78 metric tons/ha (35 tons/ac). This one application was sufficient to raise the spoil pH to a range of 6.65 - 7.35 (Tables 1, 2, 3 and 4). Data in these tables indicate that sufficient limestone, phosphorus (202 lb P_2O_5/ac) and potassium (120 lb K_2O/ac) were added to make the site acceptable to plant growth. The effects of the 1976 application was still present in the fall of 1978. There had been no appreciable lowering of pH's with time and/or irrigation (Tables 1 - 9). Fertilizer additions temporarily doubled the phosphorus level. Potassium levels were also increased to an acceptable level. Plant available phorphorus levels as anticipated declined with time. Potassium levels showed a small decrease.

Spoil Profile

Spoil samples were taken at 0 - 2.5 cm, 20.3 cm, 46 cm and 91 cm depths in all plots. These profile samples were taken in an effort to document weathering and/or leaching effects due to irrigation. Data contained in Tables 5, 6, 7 and 8 document the spoil conditions at the onset of the experimental project. These data show all layers tested exhibited low pH, low to moderate potassium levels, low phosphorus, and high calcium and magnesium levels. There was no noticeable change in pH, P, K, Ca or Mg with depth. After liming and fertilization there was a distinct change in the top layer (0 - 2.5 cm) from the deeper layers (Table 9). The top spoil layer increased to near

TABLE 1. CHEMICAL ANALYSIS OF SPOIL SAMPLES, PLOT 1, JUNE-OCTOBER 1976

Item	pH	P	K	Ca	Mg	P.A.** Metric ton/ha
		kg/ha				
	Before addition of spoil amendments					
Mean	3.2	8.4	27	2248	1328	15.4
Range	3.0-4.2	3.4-30	9-85	1760-3374	944-1687	.9-20.4
Standard Deviation		9	26	495	222	6.4
n*	8	8	8	8	8	8
	After addition of spoil amendments					
Mean	7.1	69	111	9224	1188	0
Range	7.05-7.35	22-197	93-133	8609-9584	942-1549	0
Standard Deviation		86	19	443	271	
n*	4	4	4	4	4	4

* Number of samples used to obtain the results.

** Potential acidity as the amount of agricultural limestone needed to neutralize the potential H^+ (1½ times the rate for pure $CaCO_3$).

TABLE 2. CHEMICAL ANALYSIS OF SPOIL SAMPLES, PLOT 2, JUNE-OCTOBER 1976

Item	pH	P	K	Ca	Mg	P.A.**
		kg/ha				Metric ton/ha
	Before addition of spoil amendments					
Mean	3.3	15.9	58	1908	1322	13.9
Range	3.2-3.9	10-25	12-174	1658-2229	949-1725	3.4-22.3
Standard Deviation		4.6	52	239	269	5.7
n*	8	8	8	8	8	8
	After addition of spoil amendments					
Mean	7.3	25	106	7752	1055	0
Range	0	15.7-35	97-122	1188-10480	1011-1149	0
Standard Deviation		8.0	11	4393	65	
n*	4	4	4	4	4	4

* Number of samples used to obtain the results.

** Potential acidity as the amount of agricultural limestone needed to neutralize the potential H^+ (1½ times the rate for pure $CaCO_3$).

TABLE 3. CHEMICAL ANALYSIS OF SPOIL SAMPLES, PLOT 3, JUNE - OCTOBER 1976

Item	pH	P	K	Ca	Mg	P.A.** Metric ton/ha
			kg/ha			
	Before addition of spoil amendments					
Mean	3.7	11.8	82	3816	1705	22.2
Range	3.2-4.9	9-19	18-122	2378-5437	1112-2007	12.8-32.3
Standard Deviation		3.4	38	906	319	5.4
n*	8	8	8	8	8	8
	After addition of spoil amendments					
Mean	6.8	58	151	7447	2011	0
Range	6.65-7.2	18-139	123-184	1132-9921	1717-2513	0
Standard Deviation		56.5	30.57	4218	352	
n*	4	4	4	4	4	4

* Number of samples used to obtain the results.

**Potential acidity as the amount of agricultural limestone needed to neutralize the potential H^+ (1½ times the rate for pure $CaCO_3$).

TABLE 4. CHEMICAL ANALYSIS OF SPOIL SAMPLES, PLOT 4, JUNE-OCTOBER 1976

Item	pH	P	K	Ca	Mg	P.A.**
		kg/ha				Metric ton/ha
	Before addition of spoil amendments					
Mean	2.8	19	7	2612	1343	24
Range	2.7-3.0	12-36	6-9	1502-3385	708-1597	15.3-43.4
Standard Deviation		8.2	1.3	601	338	8.4
n*	8	8	8	8	8	8
	After addition of spoil amendments					
Mean	7.1	41	87	10705	1827	0
Range	7.0-7.25	22-65	80-98	9528-11210	1603-2233	0
Standard Deviation		19	7.6	794	290	
n*	4	4	4	4	4	4

* Number of samples used to obtain the results.

** Potential acidity as the amount of agricultural limestone needed to neutralize the potential H^+ (1½ times the rate for pure $CaCO_3$).

TABLE 5. CHEMICAL ANALYSIS OF SPOIL PROFILE SAMPLES, PLOT 1, JUNE-JULY, 1976

Item	pH	P	K	Ca	Mg	P.A.** Metric ton/ha
			kg/ha			
	0-2.5 cm Depth Before addition of spoil amendments					
Mean	3.3	4.8	31	2993	1244	11
Range	3.1-4.7	2.2-7.8	17-69	1928-5549	781-1569	0-17.5
Standard Deviation		2.9	26	1710	366	7.8
n*	4	4	4	4	4	4
	20 cm Depth Before addition of spoil amendments					
Mean	3.1	5.9	22	2163	1336	15
Range	3.0-3.25	10-39	13-39	1917-2758	955-1743	10.4-19.3
Standard Deviation		4.6	13	400	429	4.1
n*	4	4	4	4	4	4

(continued)

* Number of samples used to obtain the results.

** Potential acidity as the amount of agricultural limestone needed to neutralize the potential H^+ (1½ times the rate for pure $CaCO_3$).

TABLE 5 (Continued)

Item	pH	P	K	Ca	Mg	P.A.** Metric ton/ha
			kg/ha			
	46 cm Depth Before addition of spoil amendments					
Mean	3.2	3	36	1829	710	11
Range	3.0-3.4	1-6	21-57	1077-3486	282-1227	4.4-14.4
Standard Deviation		1.9	17	1109	391	4.5
n*	4	4	4	4	4	4
	91 cm Depth Before addition of spoil amendments					
Mean	3.3	7.3	52	1657	380	5.8
Range	3.2-3.4	1-13	43-58	1457-1838	355-415	3.2-11
Standard Deviation		6.5	6.8	157.6	25	3.5
n*	4	4	4	4	4	4

* Number of samples used to obtain the results.
** Potential acidity as the amount of agricultural limestone needed to neutralize the potential H^+ (1½ times the rate for pure $CaCO_3$).

TABLE 6. CHEMICAL ANALYSIS OF SPOIL PROFILE SAMPLES, PLOT 2, JUNE-JULY 1976

Item	pH	P	K	Ca	Mg	P.A.** Metric ton/ha
		kg/ha				
	0-2.5 cm Depth Before addition of spoil amendments					
Mean	3.1	21	16	1564	1501	13.3
Range	3.0-3.3	11-28	6-40	1278-1906	549-2048	8.7-19.7
Standard Deviation		7.0	17	259	667	4.6
n*	4	4	4	4	4	4
	20 cm Depth Before addition of spoil amendments					
Mean	3.6	12	57	1300	627	8.7
Range	3.2-4.4	9-15	43-86	392-2466	258-1575	0-18.4
Standard Deviation		2.7	20.1	101	633	9.4
n*	4	4	4	4	4	4

(continued)

* Number of samples used to obtain the results.
** Potential acidity as the amount of agricultural limestone needed to neutralize the potential H^+ (1½ times the rate for pure $CaCO_3$).

TABLE 6 (Continued)

Item	pH	P	K	Ca	Mg	P.A.**
		kg/ha				Metric ton/ha
	46 cm Depth Before addition of spoil amendments					
Mean	4.1	16	106	1048	912	7.6
Range	3.9-4.7	12-19	63-149	583-1502	458-1373	0-18.6
Standard Deviation		2.9	35	512	407	9.1
n*	4	4	4	4	4	4
	91 cm Depth Before addition of spoil amendments					
Mean	4.1	10	94	970	1073	9.6
Range	3.8-4.7	8-12	85-101	437-1525	949-1233	.2-184
Standard Deviation		2.0	7	545	144	9.6
n*	4	4	4	4	4	4

*Number of samples used to obtain the results.
** Potential acidity as the amount of agricultural limestone needed to neutralize the potential H^+ (1½ times the rate for pure $CaCO_3$).

TABLE 7. CHEMICAL ANALYSIS OF SPOIL PROFILE SAMPLES, PLOT 3, JUNE-JULY 1976

Item	pH	P	K	Ca	Mg	P.A.** Metric ton/ha
		kg/ha				
		0-2.5 cm Depth Before addition of spoil amendments				
Mean	4.0	8	75	4088	3176	28.7
Range	3.7-4.6	4-12	38-117	3767-4428	1827-4848	25.2-37.5
Standard Deviation		4	40	295	1306	5.9
n*	4	4	4	4	4	4
		20 cm Depth Before addition of spoil amendments				
Mean	3.1	7.5	60	4680	1355	27.6
Range	2.8-4.9	3-12	4-117	4462-4820	1216-1435	20.4-38.4
Standard Deviation		4.9	64	154	96	7.9
n*	4	4	4	4	4	4

(continued)

* Number of samples used to obtain the results.

** Potential acidity as the amount of agricultural limestone needed to neutralize the potential H^+ (1½ times the rate for pure $CaCO_3$).

TABLE 7 (Continued)

Item	pH	P	K	Ca	Mg	P.A.** Metric ton/ha
		kg/ha				
		46 cm Depth Before addition of spoil amendments				
Mean	3.1	13.7	59	4344	1777	33.4
Range	2.9-3.9	4-22	9-118	3980-4899	1620-1928	20.4-48.5
Standard Deviation		10	56	411	156	14.4
n*	4	4	4	4	4	4
		91 cm Depth Before addition of spoil amendments				
Mean	3.3	6	36	3001	1328	29.2
Range	2.9-4.3	1-9	7-129	2298-3834	577-1984	21.1-39.3
Standard Deviation		3.6	42	764	701	9.3
n*	4	4	4	4	4	4

* Number of samples used to obtain the results.
** Potential acidity as the amount of agricultutal limestone needed to neutralize the potential H^+ (1½ times the rate for pure $CaCO_3$).

TABLE 8. CHEMICAL ANALYSIS OF SPOIL PROFILE SAMPLES, PLOT 4, JUNE-JULY 1976

Item	pH	P	K	Ca	Mg	P.A.**
		kg/ha				Metric ton/ha
	0-2.5 cm Depth Before addition of spoil amendments					
Mean	2.7	41	6	1805	2813	40.2
Range	2.65-2.9	32-48	4-8	1065-2937	645-3957	24.7-55
Standard Deviation		6.5	1.7	833	1533	13.4
n*	4	4	4	4	4	4
	20 cm Depth Before addition of spoil amendments					
Mean	2.9	16	10	3320	1312	34.4
Range	2.7-3.3	9-30	7-13	2163-4596	397-2264	30.1-40.2
Standard Deviation		11	3	1115	947	4.3
n*	4	4	4	4	4	4

(continued)

* Number of samples used to obtain the results.
** Potential acidity as the amount of agricultural limestone needed to neutralize the potential H^+ (1½ times the rate for pure $CaCO_3$).

TABLE 8 (Continued)

Item	pH	P	K	Ca	Mg	P.A.** Metric ton/ha
			kg/ha			
	46 cm Depth Before addition of spoil amendments					
Mean	2.9	37	59	3755	836	38
Range	2.6-3.9	3-84	6-118	1300-7242	356-1093	27.4-47.2
Standard Deviation		40	62	2919	337	10.4
n*	4	4	4	4	4	4
	91 cm Depth Before addition of spoil amendments					
Mean	2.9	53	54	3150	1077	42.2
Range	2.6-3.8	2-105	4-104	1424-5762	652-1605	25.6-68.1
Standard Deviation		58	57	2098	395	19.8
n*	4	4	4	4	4	4

*Number of samples used to obtain the results.
** Potential acidity as the amount of agricultural limestone needed to neutralize the potential H^+ (1½ times the rate for pure $CaCO_3$).

TABLE 9. CHEMICAL ANALYSIS OF SPOIL PROFILE SAMPLES: PLOTS 1-4, OCTOBER 1978

Plot no.		Profile depth 0-2.5 cm	20.3 cm	46 cm	91 cm
Plot 1	pH	6.5	3.2	3.2	3.2
	P*	6.9	.4	4.6	3.5
	K*	78	63	58	65
	Ca*	2003	1617	1698	1696
	Mg*	280	757	645	841
	n**	2	2	2	2
Plot 2	pH	6.8	3.2	3.2	3.4
	P	58	4.8	2.2	.3
	K	100	45	54	56
	Ca	2008	1891	1690	1632
	Mg	336	448	700	729
	n	2	2	2	2
Plot 3	pH	7.5	3.3	3.5	3.6
	P	58	5.3	7.8	6.7
	K	87	25	41	103
	Ca	2023	1977	1954	1896
	Mg	1541	1457	1460	1373
	n	2	2	2	2
Plot 4	pH	6.5	3.1	3.1	3.8
	P	25	4.8	7.0	.6
	K	71	11	13	83
	Ca	2027	1992	1970	1846
	Mg	869	700	785	925
	n	2	2	2	2

* Values are expressed in kg/ha.
** Number of samples used to obtain the results.

TABLE 10. RESULTS* OF PARTICLE SIZE ANALYSIS OF COMPOSITE SPOIL SAMPLES (2.5-15 cm IN DEPTH) FROM THE VOGUE-EPA PROJECT: MUHLENBERG COUNTY, KENTUCKY, 1976.

Sample	Percent distribution of particle sizes		
	Sand (>50μm)	Silt (50-2μm)	Clay (<2μm)
Plot 1	54.5	29.6	16.0
Plot 2	51.4	32.7	15.9
Plot 3	46.2	35.8	18.0
Plot 4	48.3	35.1	16.6
Mean	50.1	33.3	16.6

*Analysis made by Dr. R.I. Barnhisel, University of Kentucky.

neutral pH's (6.5 - 7.5); phosphorus and potassium increased to significantly higher levels. Calcium levels appeared to be higher in the surface layers than the deeper layers (Table 9). No other appreciable differences were noticed in the plots with depth (Table 10).

WATER QUALITY DATA

During 1976, initial attention was devoted to performance of the water monitoring and functioning of the irrigation system. Baseline data were collected on the raw water, treated water, and runoff water from the plots (Table 11 and Figures 2-10). The surface mine pit used for a raw water source tended to increase in acidity between December 1974 and October 1978 (Table 11). The changes in water quality of the pit did not influence the type of treatment employed (limestone). It was possible to produce acceptable water, pH 6, even at the higher acidity values with limestone treatment.

Table 12 shows the amount of water treated for irrigation of the plots. The individual irrigation periods were equal to approximately a 2.5 cm (one in.) precipitation event. Irrigation intensity was varied in 1978 from 1.7 cm to 3.0 cm (.66 in. to 1.20 in.) of treated water/ac.

Data in Table 13 are chemical analyses of applied water. It can be noted that applied water's acidity of plots 1 and 4 has tended to increase with time. In addition, applied water has increased in iron and manganese on all plots.

pH

Plot 1 - Treated Water With Sludge
This treatment consistently produced water which was well above a pH of 6.0 (Figure 2). Applied water ranged from 6.5 to 7.7; while runoff water varied from 6.2 to 7.3. The runoff water closely matched the applied water pH (Figure 2). The application of irrigation water to this plot did not tend to increase or decrease the pH of irrigation runoff water. Plot 1's runoff water was significantly higher in pH than the raw water plot (Plot 4).

Plot 2 - Treated Water Without Sludge
As with plot 1, this treatment always produced water with pH's in excess of 6.0. Applied water pH was slightly lower than that for plot 1. Unlike plot 1, however, in practically every case the irrigation runoff water had increased in pH upon leaving the plot. The increase was normally only .2 to .4 of a pH unit. Since the water was clarified, no rock dust was suspended in the irrigation water. These increased runoff values of pH were due to irrigation on plot 2. The increase in pH was probably a reflection of two factors. Carbon dioxide

TABLE 11. CHEMICAL ANALYSIS OF RAW WATER SOURCE USED FOR IRRIGATION, 1974-1978

Date of sample	pH	mg/l	
		Acidity	Alkalinity
Dec. 11, 74	4.0	116	0
Dec. 20, 74	4.0	98	0
April 15, 75	3.8	148	0
Oct. 11, 76	3.7	108	0
Oct. 15, 76	3.7	108	0
Nov. 2, 76	3.6	160	0
Nov. 4, 76	3.8	168	0
May 24, 77	3.4	196	0
July 8, 77	3.2	376	0
July 27, 77	3.2	446	0
Aug. 10, 77	3.1	450	0
Aug. 23, 77	2.7	506	0
Sept. 13, 77	2.9	522	0
Oct. 16, 78	2.9	844	0
Oct. 25, 78	3.0	844	0

TABLE 12. IRRIGATION SCHEDULE AND VOLUMES OF WATER APPLIED TO EACH PLOT, 1976-1978

Date	Plot	Irrigation time*	Volume of water m^3/d**	cm	Application cm/hr	Type*** water
10/11/76	4	4	164.3	2.3	.58	raw
10/15/76	1	5½	174.5	2.5	.46	tr+slu
10/21/76	2	2½	107.5	1.5	.61	tr+slu
11/2/76	4	4¼	171.5	2.5	.58	raw
11/4/76	1	4½	189.3	2.8	.61	tr+slu
6/1/77	1	4	163.5	2.4	.61	tr+slu
6/8/77	1	4¼	170.7	2.5	.58	tr+slu
7/28/77	1	4	157.5	2.3	.58	tr+slu
8/25/77	1	4	153.7	2.2	.56	tr+slu
9/1/77	1	4	154.1	2.2	.56	tr+slu
6/21/77	1	4	158.6	2.3	.58	tr+slu
10/10/77	1	4	146.5	2.1	.53	tr+slu
6/3/77	2	2	115.8	1.7	.84	tr-slu
8/9/77	2	3½	152.2	2.2	.63	tr-slu
8/24/77	2	4	155.9	2.3	.58	tr-slu
8/26/77	2	4	151.4	2.2	.56	tr-slu
9/2/77	2	4	152.9	2.2	.56	tr-slu
9/23/77	2	4	164.3	2.4	.61	tr-slu
5/24/77	4	4	151.4	2.2	.56	raw
6/7/77	4	4½	171.5	2.5	.56	raw
7/27/77	4	4	132.9	1.9	.48	raw
8/10/77	4	4	138.2	1.9	.51	raw
8/23/77	4	4	153.3	2.2	.56	raw
9/13/77	4	4	151.8	2.2	.56	raw
10/6/77	4	4½	180.9	2.6	.56	raw
10/5/78	1	4	142.3	2.0	.51	tr+slu
10/6/78	1	4½	127.6	1.8	.41	tr+slu
10/17/78	1	4⅛	115.8	1.7	.41	tr+slu
10/25/78	1	5⅛	209.7	3.0	.56	tr+slu
11/8/78	1	5	180.5	2.6	.51	tr+slu

*Time in hours.
**Total m^3/d (cubic meters) = 4660.1 (1,231,200 gal).
***tr+slu + treated water with sludge and tr-slu = treated water withou sludge.

TABLE 13. CHEMICAL ANALYSIS OF WATER APPLIED TO PLOTS, 1976-1978

			mg/l					
Date	Plot*	pH	Acidity	Alkalinity	Iron	Mn	TSS	TDS
10/11/76	4	3.7	108	0	--	--	--	--
10/15/76	1	6.8	18	56	--	--	--	--
10/21/76	2	6.6	10	50	--	--	--	--
11/2/76	4	3.6	160	0	--	--	--	--
11/4/76	1	6.7	15	56	--	--	--	--
5/24/77	4	3.4	196	0	4.6	45.2	--	--
6/1/77	1	7.1	58	38	5.6	47.3	--	--
6/3/77	2	5.8	104	8	22.5	47.3	--	--
7/27/77	4	3.2	446	0	36.0	49.1	40.8	4285
7/28/77	1	6.8	36	84	40.2	51.3	1272.2	4281
8/9/77	2	6.2	40	56	3.9	52.1	12.5	4507
8/10/77	4	3.1	450	0	38.6	44.6	.7	4511
8/23/77	4	2.7	506	0	53.2	40.0	30.1	3754
8/24/77	2	6.2	14	48	2.3	28.4	17.0	3807
8/25/77	1	6.7	0	128	58.0	47.1	764.0	3874
8/26/77	2	6.2	34	58	1.8	29.3	11.0	3854
9/1/77	1	7.7	0	82	55.2	43.7	712.0	3971
9/2/77	2	7.5	8	60	4.3	38.9	22.0	3929
9/13/77	4	2.9	522	0	51.5	46.9	13.0	4364
9/21/77	1	6.5	0	100	57.4	43.9	849.0	4338
9/23/77	2	6.5	18	86	1.8	42.5	11.0	4364
10/10/77	1	6.8	0	138	--	--	460.0	4276
10/6/78	1	6.9	--	170	44.5	72.7	--	--
10/17/78	1	6.8	256	172	149.6	66.9	--	--
10/25/78	1	7.5	20	172	156.7	80.6	--	--

* 1 - Treated water with sludge
  2 - Treated water without sludge
  3 - Control
  4 - Raw water

is a by-product of limestone reaction with acid water, (Wilmoth, et al, 1972). This carbon dioxide will suppress the water pH until it is released. Irrigation of the water probably released the excessive amount of carbon dioxide. The other probable reason for pH increase could be the contact of the irrigation water with agricultural limestone present on the plot. The noted increase was probably due to a combination of these two factors.

Plot 4 - Raw Water
Water applied to this plot received no treatment. Applied water pH's ranged from 3.75 - 2.7. Irrigation runoff water values from this plot consistently increased over the applied water values.

Runoff water values increased in pH as a result of being irrigated onto this plot. Water pH's were increased to above 6.0 until July 1977 (Figure 4). After July 1977 the acidity of the raw water had apparently increased to a point that exceeded the capacity of the residual agricultural limestone to raise the runoff water to a pH of 6.0 (Tables 11 and 13). Even though a pH of 6.0 was not achieved there was still a significant increase (1 to 2 pH units) in pH of applied water after July 1977 (Figure 4). Evidently the residual limestone of plot 4 was still in a reactive state, however the plot could not produce pH 6.0 water at the high acidity concentrations.

Acidity

Irrigation runoff water from the plots showed changes in acidity values with respect to the year irrigation took place. The small amount of irrigation that took place in 1976 showed zero acidity for runoff of plots 1 and 2 (treated water) and small to zero amounts for untreated water (plot 4). However, in 1977 acidity values were present in runoff of plots 1 and 2 as well as plot 4.

Plot 1 - Treated Water With Sludge
As previously indicated, this plot as well as plot 2 produced water with little or no acidity during 1976 (Figure 5). During 1977, as the acidity of the raw water increased, the acidity of the irrigation runoff water increased (Table 11). Even with the increase in acidity, alkalinity always exceeded acidity. Therefore no net acidity was present.

The increase of irrigation runoff acidity was due to the inability of a once through limestone treatment:

1. to react rapidly and

2. increase pH sufficiently high to cause rapid oxidation of major dissolved metals (iron and manganese).

It is notable that despite the increases in acidity from approximately 100 mg/l to 844 mg/l, the applied water to plot 1 was maintained at pH of 6.0 or greater. However, in order to maintain a pH of 6.0 or greater, large increases in limestone rates were necessary. This was consistent with published data (Wilmoth, 1974) showing that as the desired pH effluent increased the amount of limestone (rock dust) increased at a more rapid rate.

Plot 2 - Treated Water Without Sludge

Plot 2 produced water with no acidity during 1976 but acidity was present from runoff during 1977. The apparent reasons for the increases were the same as for plot 1 (increases in raw water acidity). However the irrigation runoff water was notably lower in acidity than the treatment of treated water with sludge (Figure 6). This difference was believed due to the long detention and hence reaction time (16 - 24 hours storage in clear water lagoon) of irrigation water for plot 2. This allowed a major portion of the total iron concentration to be removed from the irrigation water and hence its contribution to total acidity was diminished (Table 13). Runoff water (plot 2) due to irrigation had significantly lower acidity values than the raw water plot (Plot 4; Figure 6 and 7).

Plot 4 - Raw Water

Irrigation runoff water from this plot increased in acidity with time (Figure 7). Increases in applied water acidities caused increases in runoff acidities. During a day's irrigation run, initial runoffs from the raw water plot were usually lowest in acidity. This was not generally true for plots 1 or 2. Irrigation of raw water to plot 4 caused reduction to applied water acidities from 65 (1977 data) to 100 percent (1976 irrigation). Undoubtedly this change in acidity was due to the reaction of acidic water with residual agricultural limestone present.

Alkalinity

All plots produced irrigation runoff water with alkalinity (Figures 8, 9 and 10). There was a general diminishing of alkalinity with time from start of irrigation runoff until shutdown of each run. This established a trend that was also discernible monthly.

Plot 1 - Treated Water With Sludge

The alkalinity of the irrigation runoff from this plot always exceeded its acidity (Figures 5 and 8). Alkalinity tended to be highest with first irrigation runoff. Alkalinity of runoff tended to be less than the applied alkalinity. Evidently there was some deposition of alkalinity (rock dust) onto the plot. Irrigation runoff values were significantly higher than plot 4 (raw water) but no significant difference was noted between plots 1 and 2.

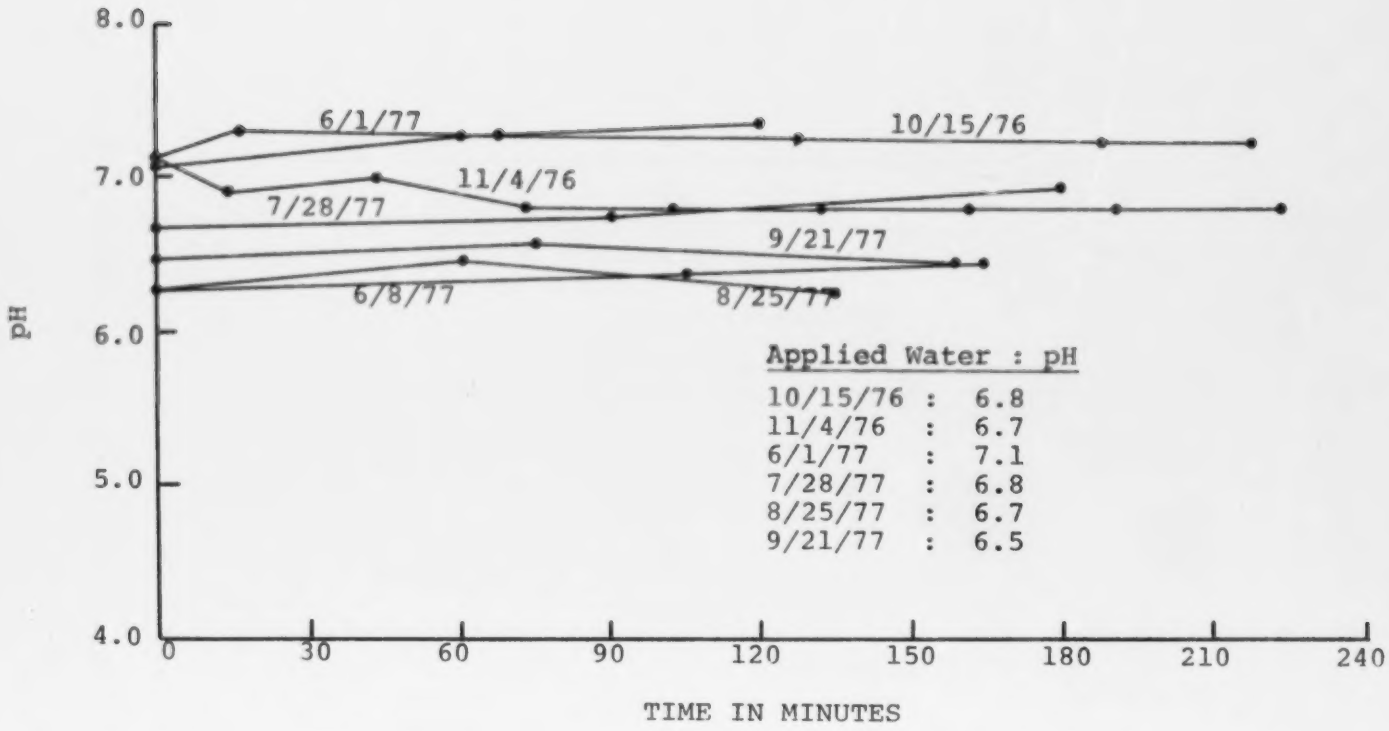

Figure 2. Analysis of discharge water from Plot 1, treated water with sludge, 1976-1977.

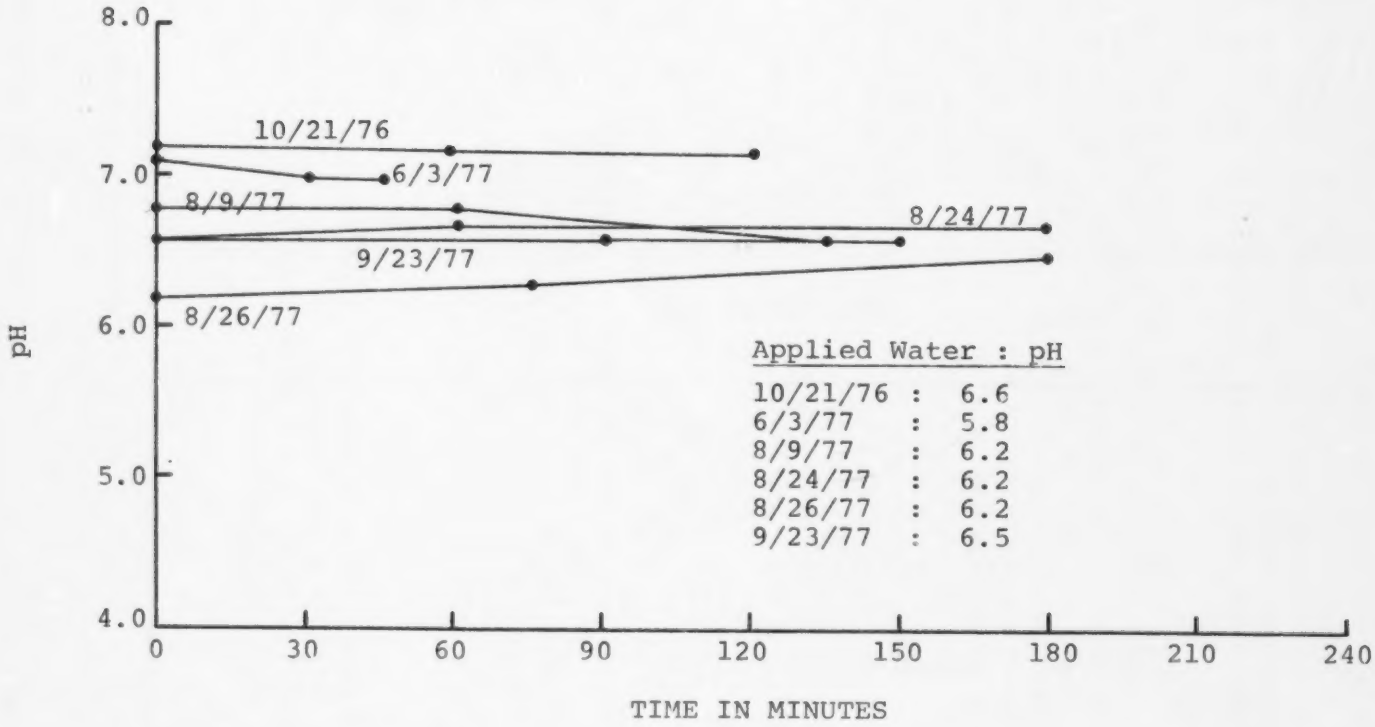

Figure 3. Analysis of discharge water from Plot 2, treated water without sludge, 1976-1977.

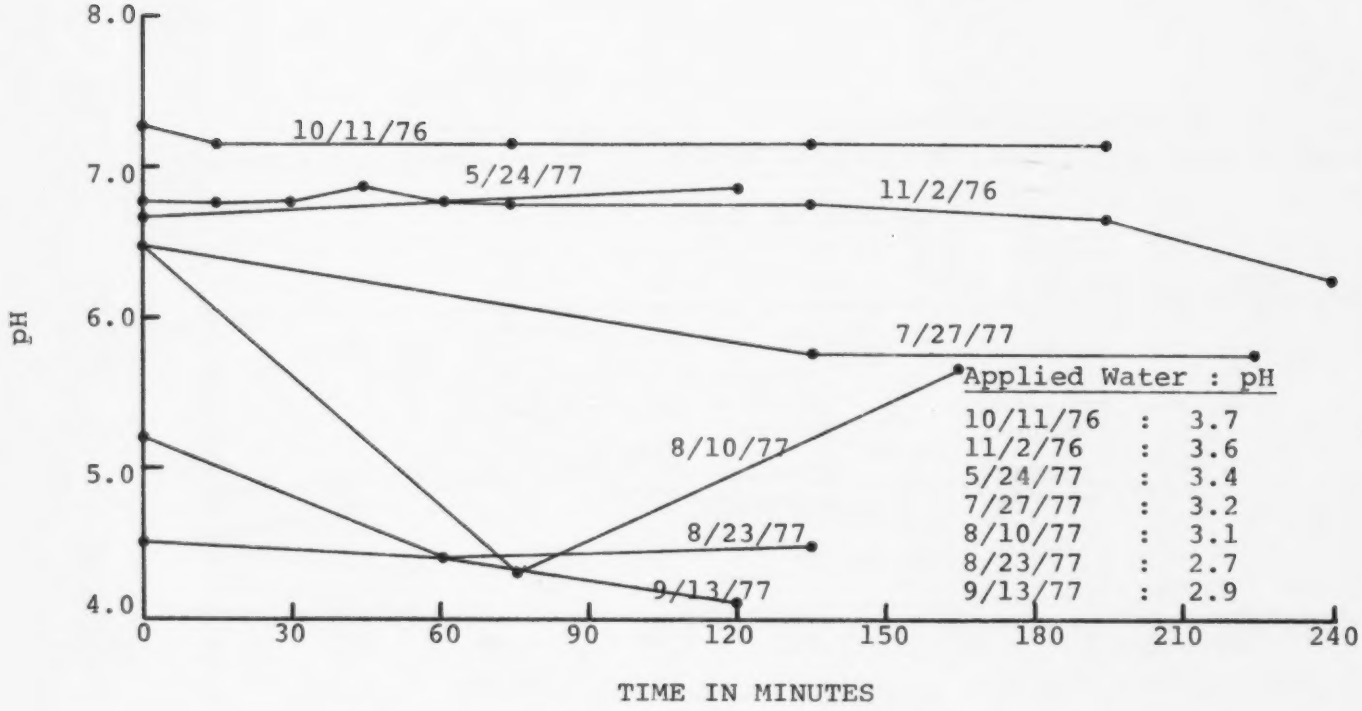

Figure 4. Analysis of discharge water from Plot 4, raw water, 1976-1977.

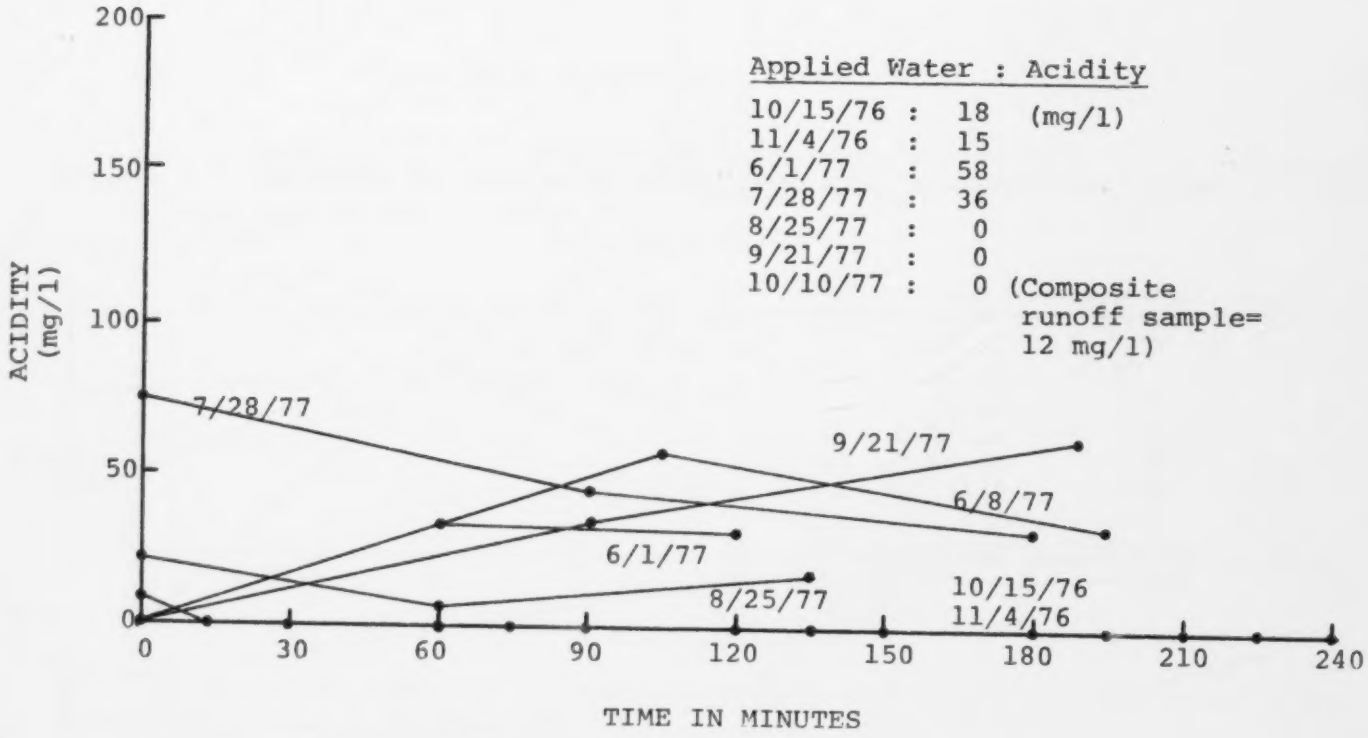

Figure 5. Analysis of discharge water from Plot 1, treated water with sludge, 1976-1977.

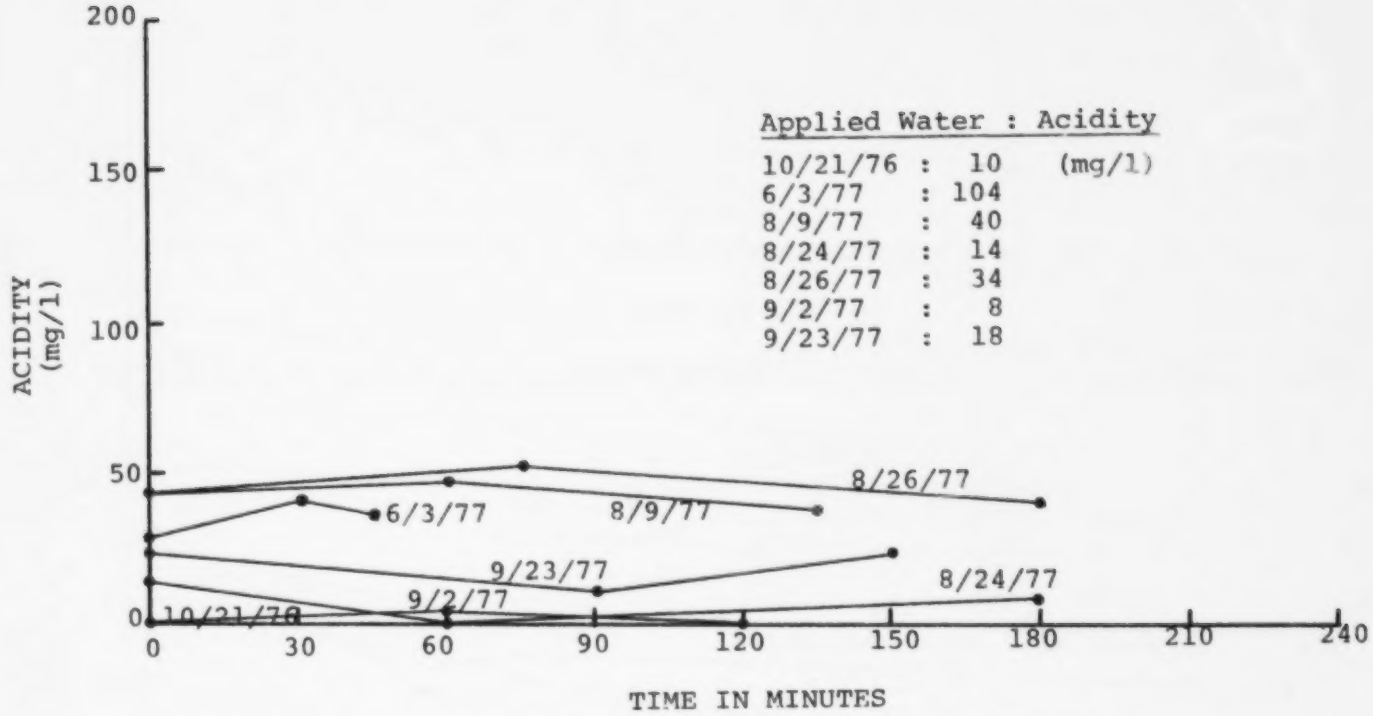

Figure 6. Analysis of discharge water from Plot 2, treated water without sludge, 1976-1977.

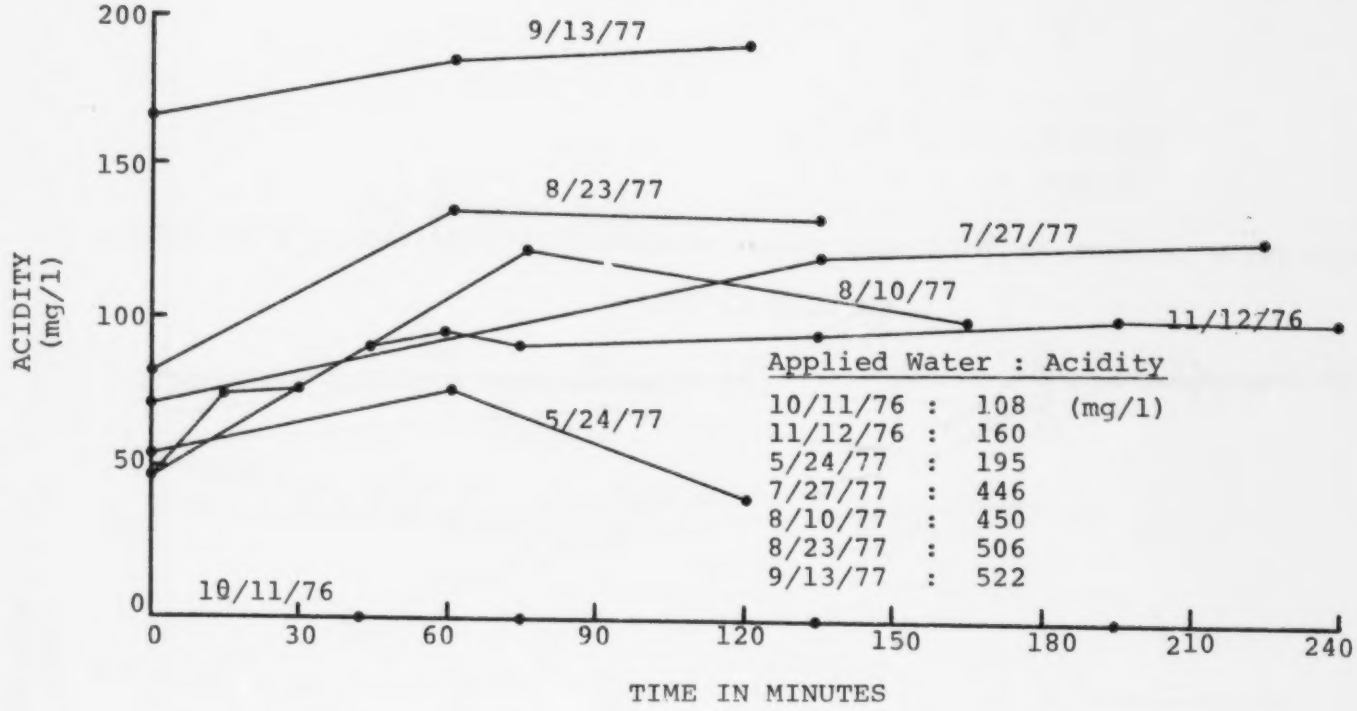

Figure 7. Analysis of discharge water from Plot 4, raw water, 1976-1977.

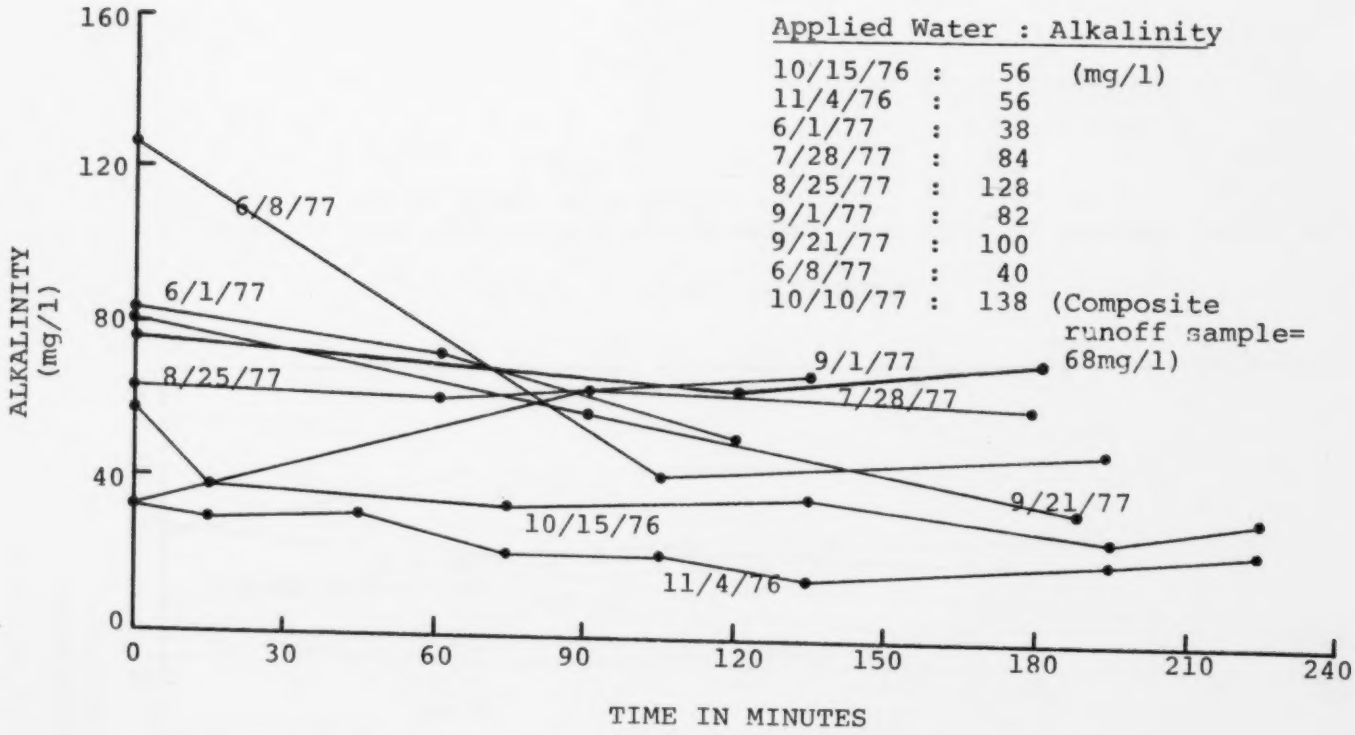

Figure 8. Analysis of discharge water from Plot 1, treated water with sludge, 1976-1977.

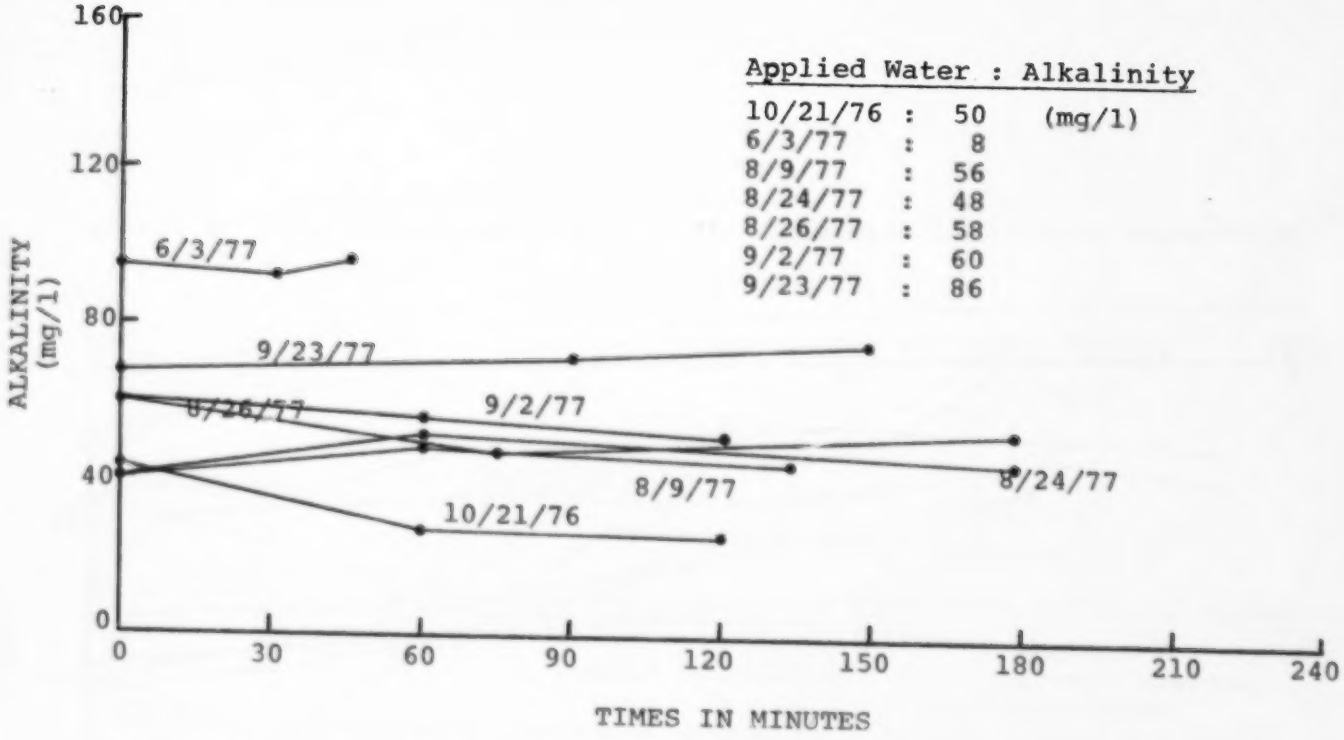

Figure 9. Analysis of discharge water from Plot 2, treated water without sludge, 1976-1977.

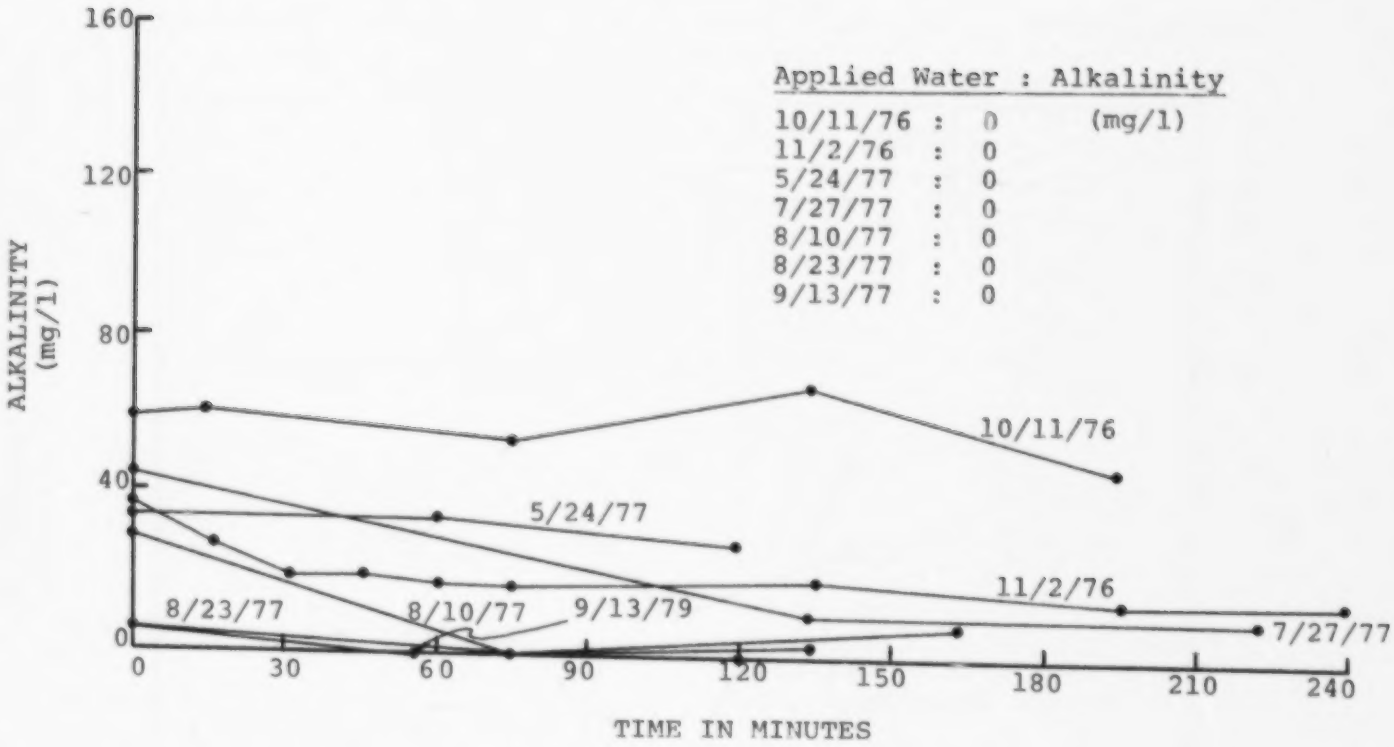

Figure 10. Analysis of discharge water from Plot 4, raw water, 1976-1977.

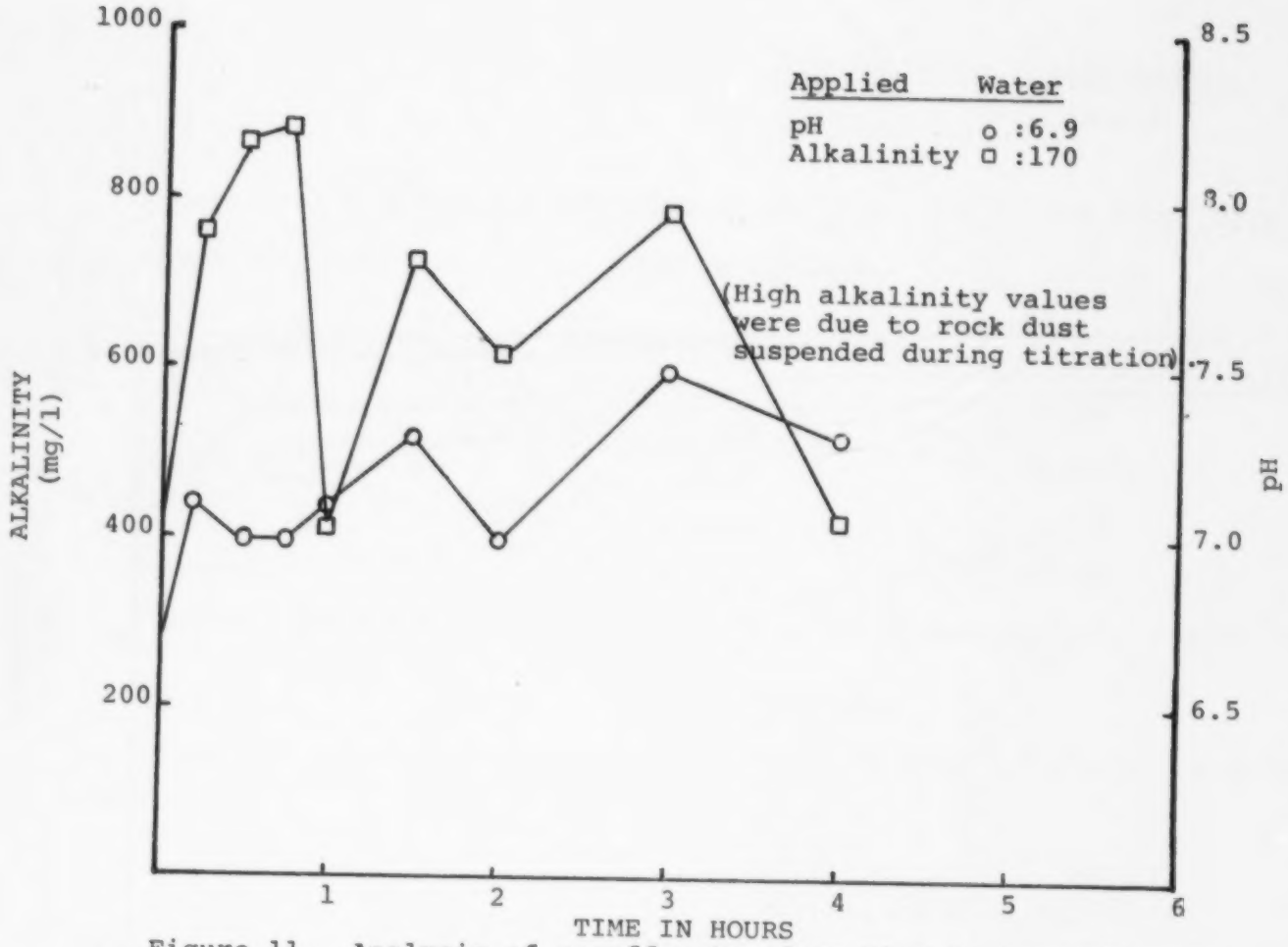

Figure 11. Analysis of runoff water from Plot 1, treated water with sludge, 6 October 1978.

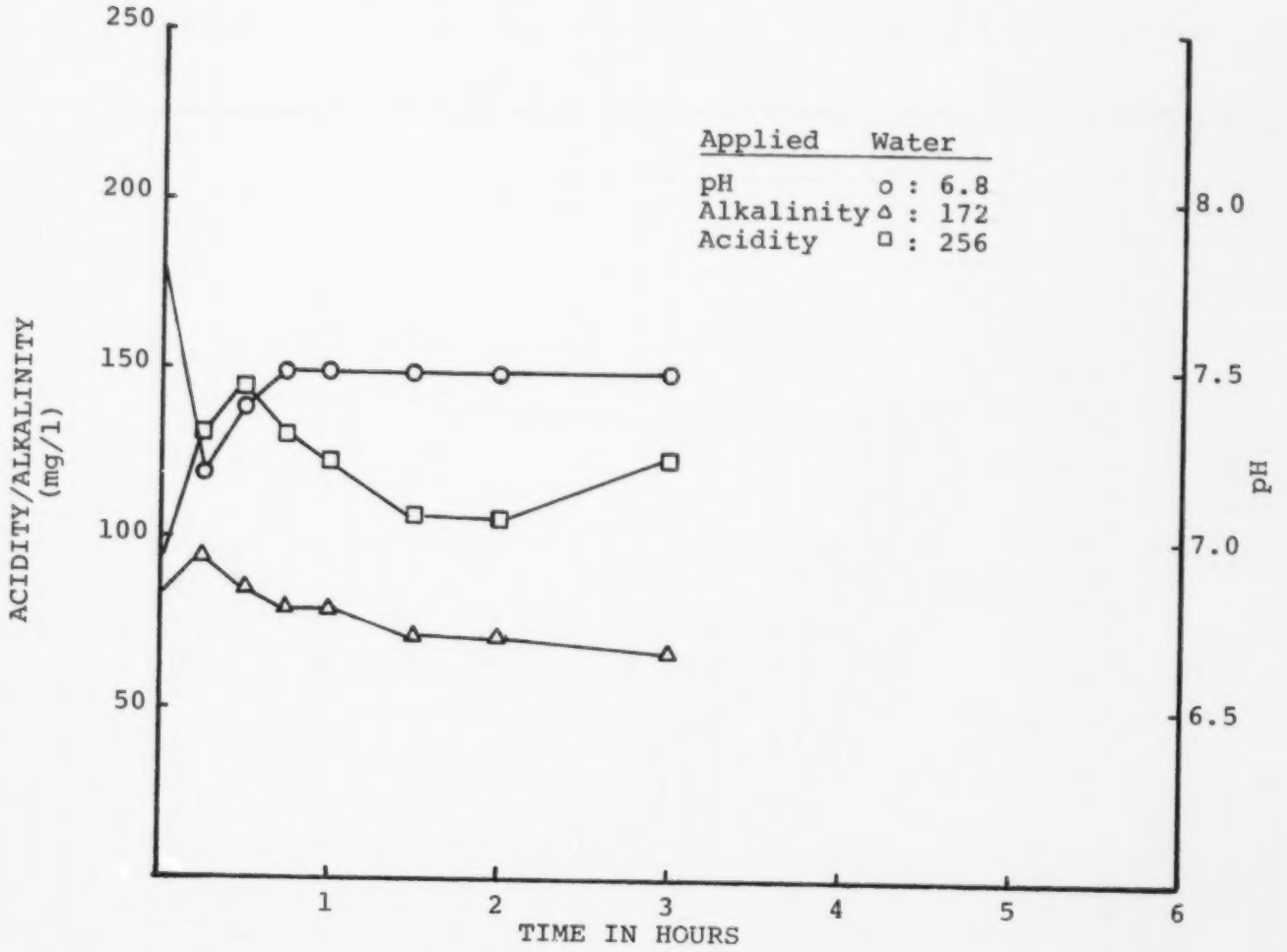

Figure 12. Analysis of runoff water from Plot 1, treated water with sludge, 17 October 1978.

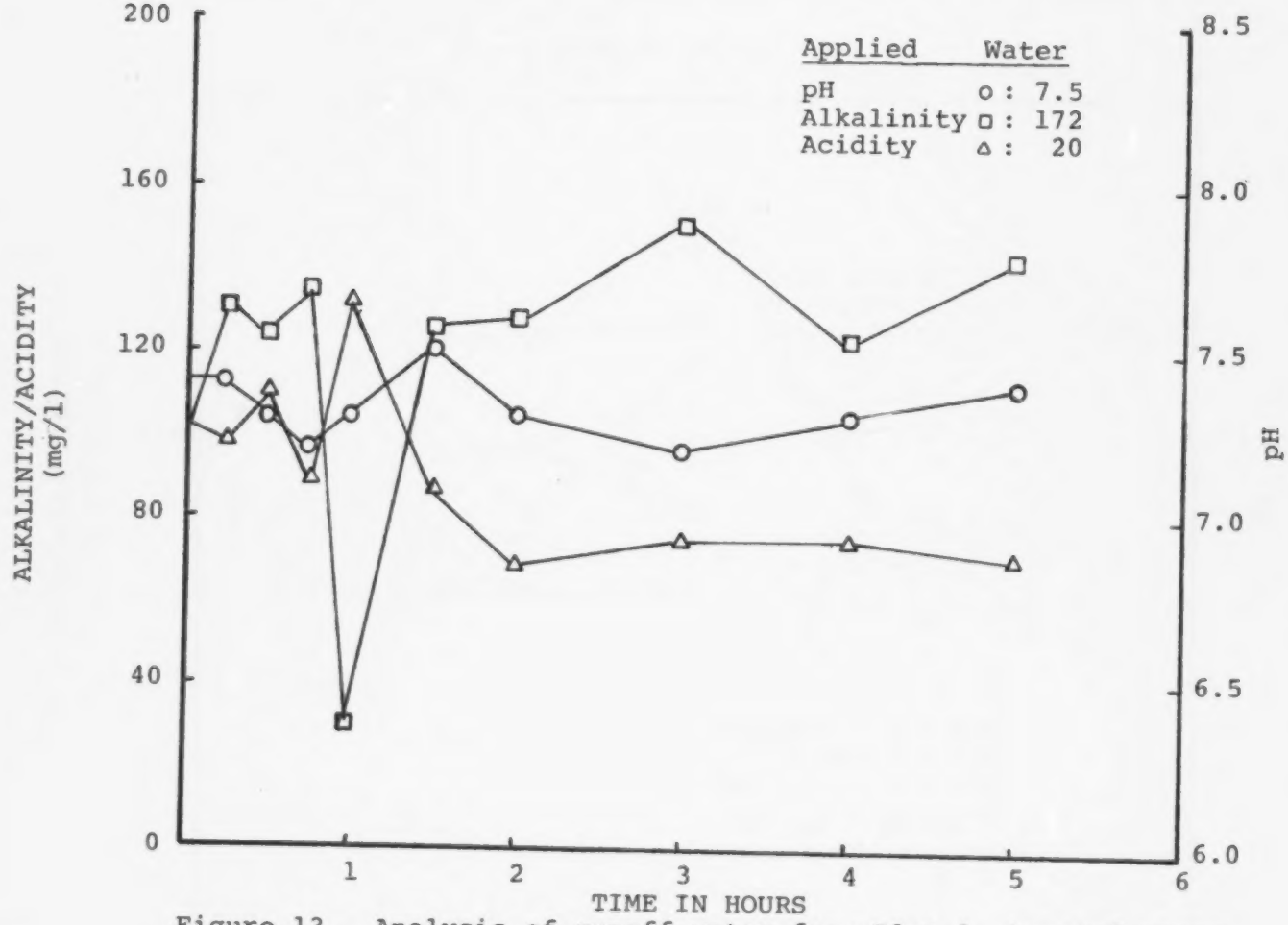

Figure 13. Analysis of runoff water from Plot 1, treated water with sludge, 25 October 1978.

Plot 2 - Treated Water Without Sludge
Irrigation runoff from this plot did not exhibit the amplitude of values for a single irrigation run as plot 1 exhibited (Figures 8 and 9). Unlike plots 1 and 4, this plot tended to produce as high, or higher, alkalinity runoff at the end of the irrigation cycle as recorded at the first runoff. Alkalinity values were significantly higher than the raw water plot.

Plot 4 - Raw Water
This plot produced water with alkalinity (except 13 September 1977) even though the applied water contained no alkalinity (Figure 10). Alkalinity of irrigation runoff tended to be greatest at initial runoff and diminish with time (Figure 10). Runoff alkalinity varied inversely with acidity of applied water (Table 13 and Figure 10).

Iron

Plot 1 - Treated Water With Sludge
Discharge water from this plot was always high in iron (Figures 14, 15, 16, 20, 21, 22 and 23). However, lowest values of iron were achieved from first runoff after irrigation started. Runoff from this plot would not meet EPA discharge limits of 3.5 - 7 mg/l. There appeared to be an initial lag in increase of iron concentration with regards to an increase in flow (Figures 20, 21, 22 and 23). The high initial iron concentration of discharge water in 1977 was apparently linked with suspended solids and rigorous digestion procedure followed for total metal determination. In late 1977 EPA Region IV approved a "soft" digestion procedure which called for a shorter digestion time in hot HNO_3-HCL (EPA, 1974). This newer procedure was used at Peabody Coal Company's Kentucky Regional Laboratory which completed these analyses. The later analyses probably gave a more accurate picture of the amount of iron in the water either as precipitated iron ($Fe(OH_2)$, dissolved iron or loosely held iron on soil particles. However, the more rigorous digestion actually determines the amount of iron in the water and sediment. By comparing Figures 14 and 24 a high degree of correlation between suspended solids and iron can be noted.

For purposes of interpretation of iron in discharge water, the author believes 1978 data gives a clearer picture of "free iron" contributed from mining activities rater than the more rigorous digestion procedures. After an initial lag (approximately 30 minutes to 1½ hours depending on irrigation rate) time of lower iron concentrations, iron values would rise to higher levels and be maintained. At the discontinuance of irrigation, the reduced runoff volumes did not indicate a marked downward dip in iron concentrations. This correlates with suspended solids loads which remained at a relatively high level at the end of irrigation (Figure 24).

Plot 2 - Treated Water Without Sludge
This plot (clear water effluent) produced runoff water with initially high iron readings. The initial high iron values were thought to be correlated with suspended solids which were also highest initially (Figures 15 and 25). Since these tests were in 1977, all water samples from this plot were pretreated with a rigorous acid digestion. In most instances the lowest iron values were obtained from the later runoffs (lower suspended solids). The runoff from this plot was significantly lower than iron concentrations of plot 1. The difference between plots 1 and 2 could be attributed to the lower concentration of iron in the applied water of plot 2 (Figure 15). No significant difference was apparent between plots 2 and 4 (raw water). This plot did produce water below 7 mg/l of iron on several occasions.

Plot 4 - Raw Water
As in plots 1 and 2 the largest iron values were recorded at initial runoff. These high initial concentrations were correlated with high suspended solids at first flows (Figures 16 and 26). Lowest concentrations were noted toward the end of the irrigation period. This plot did produce water below the maximum effluent limit of 7.0 mg/l of iron on one occasion.

Manganese

None of the plots produced runoff water from irrigation that would meet current discharge limits for manganese. All values were much higher than the allowable limit of a maximum of 4.0 mg/l. Manganese did not exhibit the large amplitude in values that iron exhibited. The lag phase was not pronounced.

Plot 1 - Treated Water With Sludge
Initial runoff was always lower in concentration than later discharge. The lag time in manganese was not very pronounced. In addition, manganese values did not have a great amplitude (Figure 17). Values obtained in 1977 showed little change in manganese concentration from initial flows to latter discharges.

A typical range of manganese in an irrigation run would start at 45 mg/l and peak at 65 mg/l (Figures 20-23). The runoff values did not vary greatly from the manganese concentrations of the applied water. Once the short lag phase was over, manganese concentration did not greatly fluctuate.

Plot 2 - Treated Water Without Sludge
Manganese values were comparable to levels obtained in plot 1 (Figures 17 and 18). The difference between manganese levels of plots 1 and 2 was not significant. However plot 1 data were significantly lower in manganese than plot 4's runoff (raw water plot). Manganese has a slow oxidation rate at moderate pH levels of 6.0 -7.0. The pH's achieved during neutralization

using rock dust would seldom exceed a pH of 6.0 - 6.3. Even with settling the treated water 16-24 hours, the manganese values did not appreciably lower. This phenomenon was not unexpected as numerous researchers (Strumm and Morgan, 1970) have reported little success of rapid oxidation of this metal unless at pH values of 8.5 - 10.0. Manganese levels did not appreciably differ from applied manganese values (Figure 18). Plot 2 irrigation runoff was significantly lower than plot 4 with regards to manganese levels.

Plot 4 - Raw Water
This plot consistenly produced water with high manganese levels. Manganese levels were significantly higher than irrigation runoff of plots 1 or 2. Runoff values of manganese were not appreciably higher than applied manganese levels.

Suspended Solids

All plots showed initial suspended solids (TSS) peaks with first flows. This trend appeared to be consistent with all three plots (Figures 24, 25, and 26).

Plot 1 - Treated Water With Sludge
This plot produced higher suspended solids loads than either plots 2 or 4. Suspended solids loads were never close to EPA's effluent standards of 35-70 mg/l. The high values were undoubtedly due to suspended matter in the irrigation water as well as suspended spoil material washed from the soil surface (Figure 31).

Plot 2 - Treated Water Without Sludge
Runoff from this plot produced water with approximately one-half the suspended solids load of plot 1 (Figures 24 and 25). However this plot did not produce water of significantly lower TSS content than plot 4. Runoff of this plot would not meet EPA's effluent standards for TSS. Runoff values of TSS were significantly higher than applied levels (Figure 25).

Plot 4 - Raw Water
This plot produced the characteristic initial high peak loads of suspended solids. This peak was followed by lower values (Figure 26). Runoff from this plot was slightly lower in suspended solids than plot 2, but the difference was not significant. Runoff from this plot would not meet effluent limits for TSS. As with plots 1 and 2, irrigation runoff values of TSS were significantly higher than applied TSS levels.

Dissolved Solids

Dissolved solids values showed no discernible trend as to peak or low values during a irrigation cycle. However, all plots produced irrigation runoff water which was higher than the TDS

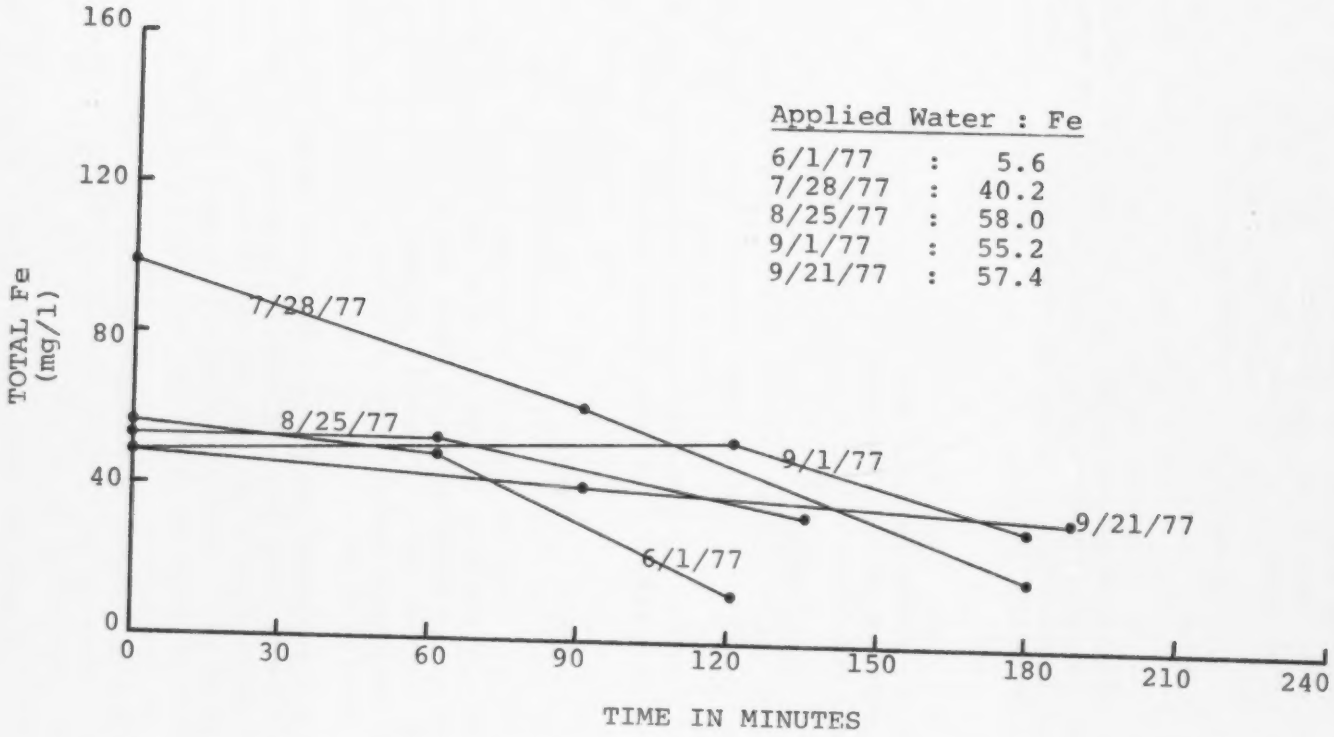

Figure 14. Analysis of discharge water from Plot 1, treated water with sludge, May-October 1977.

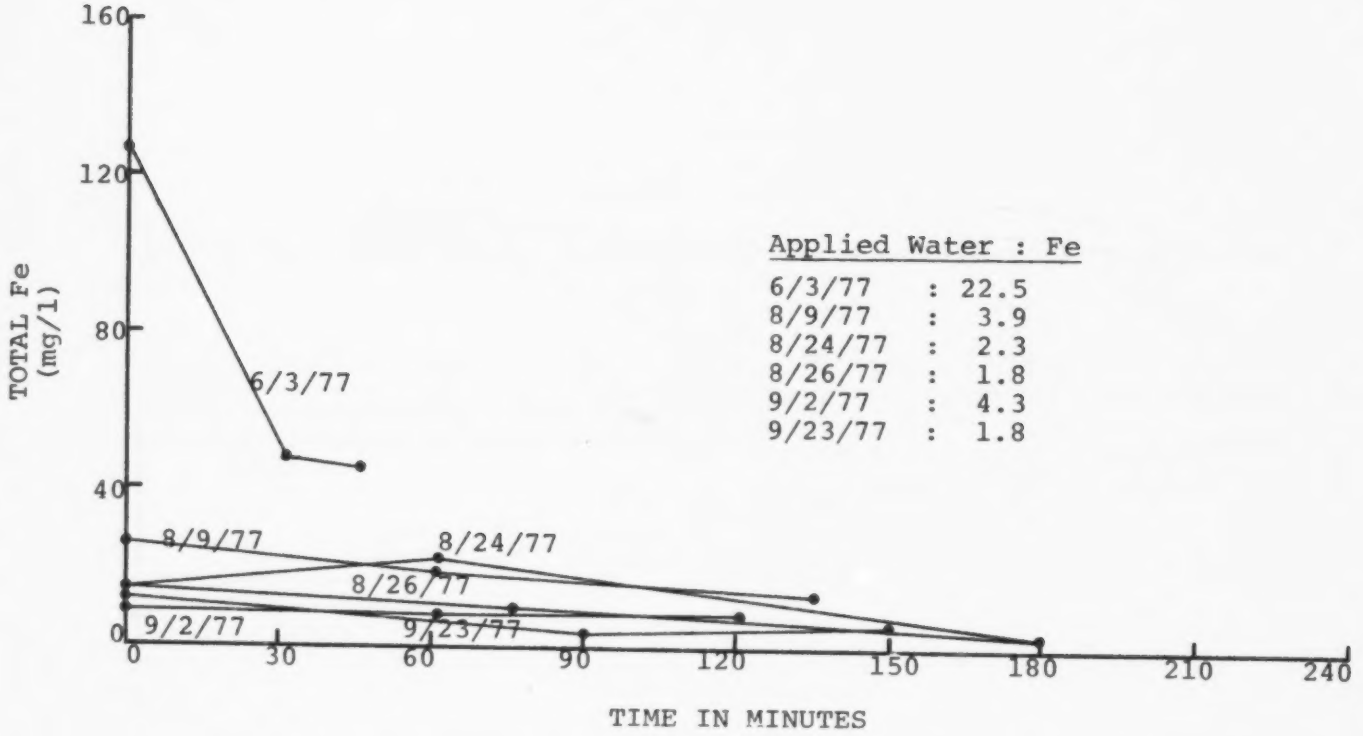

Figure 15. Analysis of discharge water from Plot 2, treated water without sludge, May-October 1977.

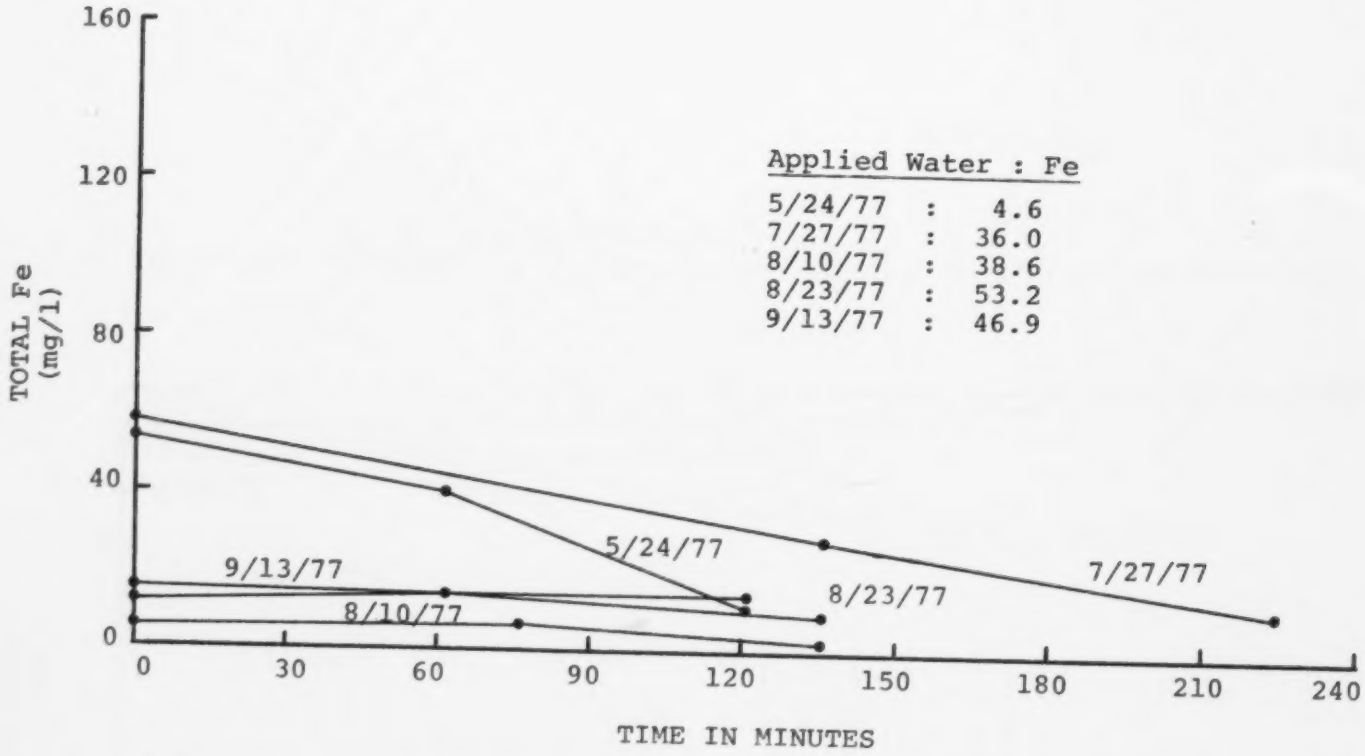

Figure 16. Analysis of discharge water from Plot 4, raw water, May-October 1977.

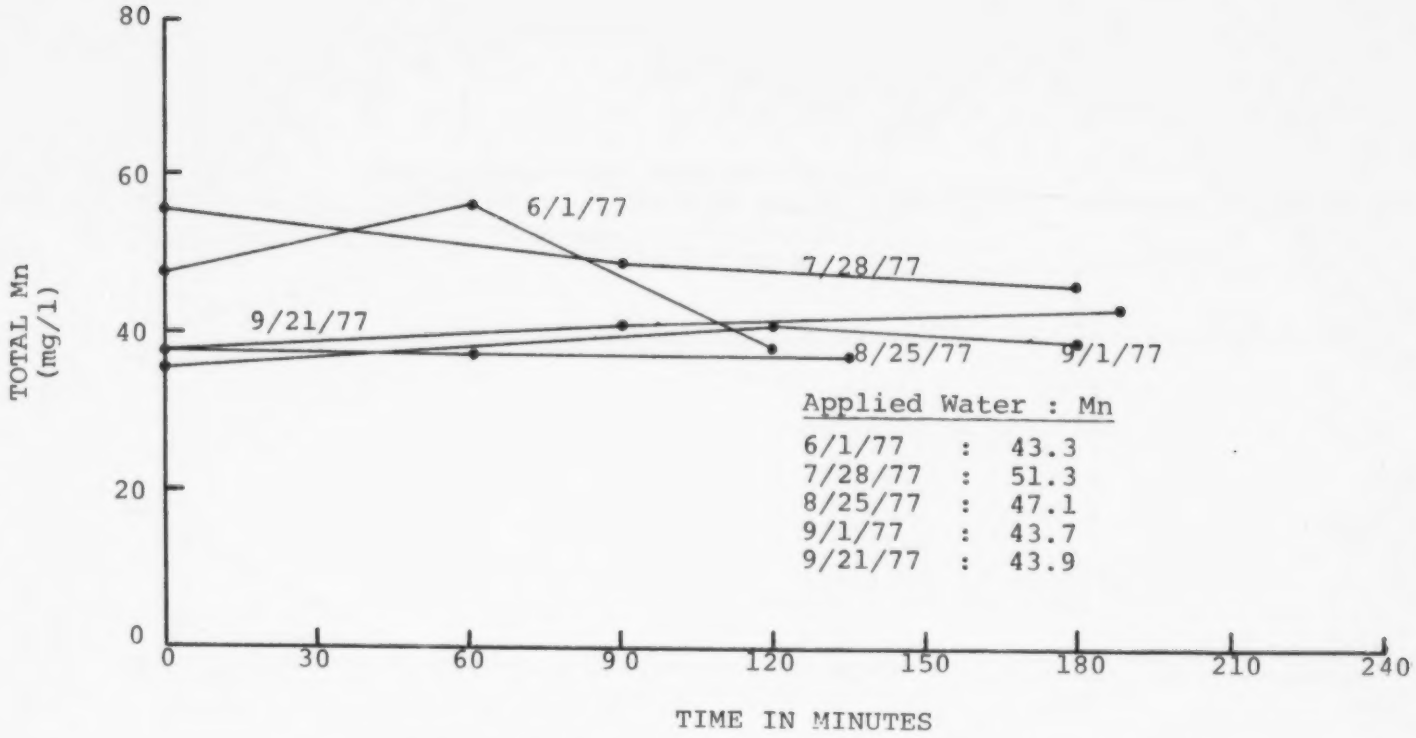

Figure 17. Analysis of discharge water from Plot 1, treated water with sludge, May-October 1977.

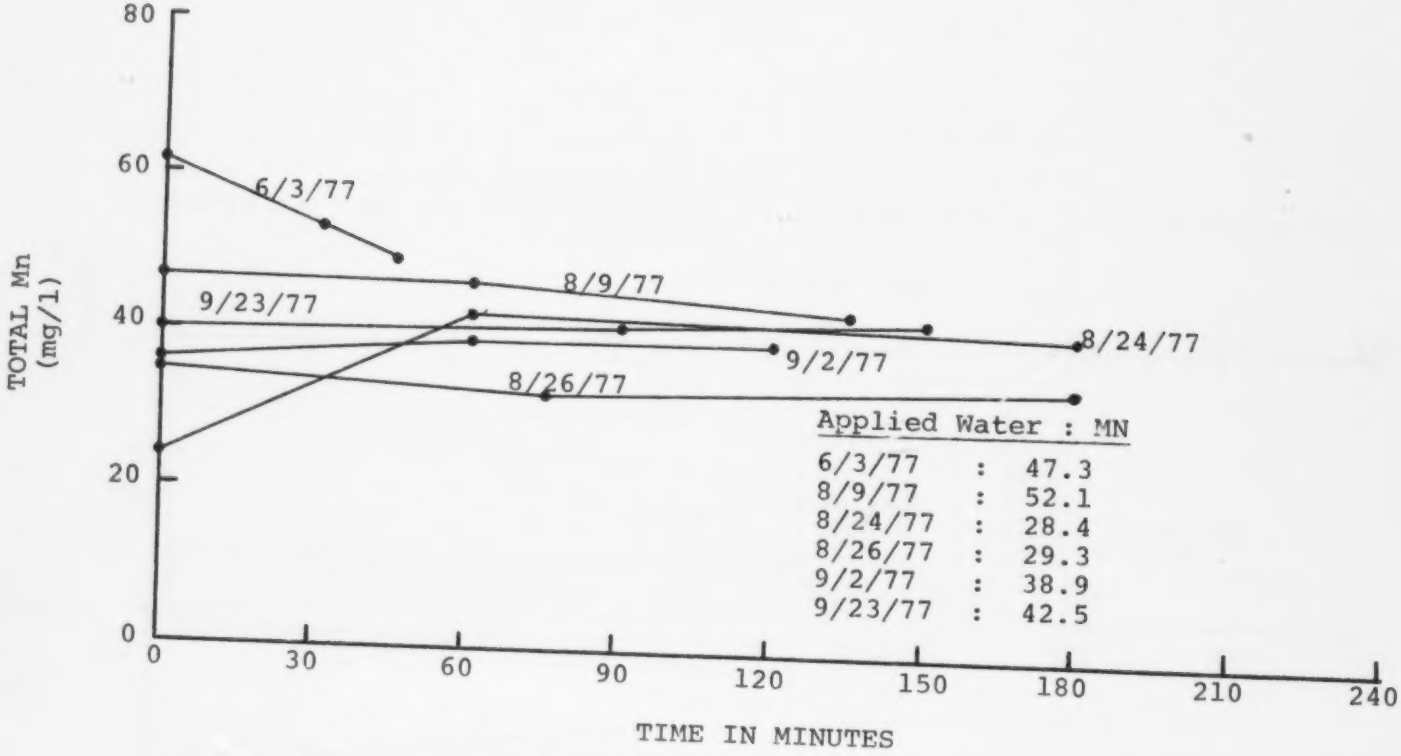

Figure 18. Analysis of discharge water from Plot 2, treated water without sludge, May-October 1977.

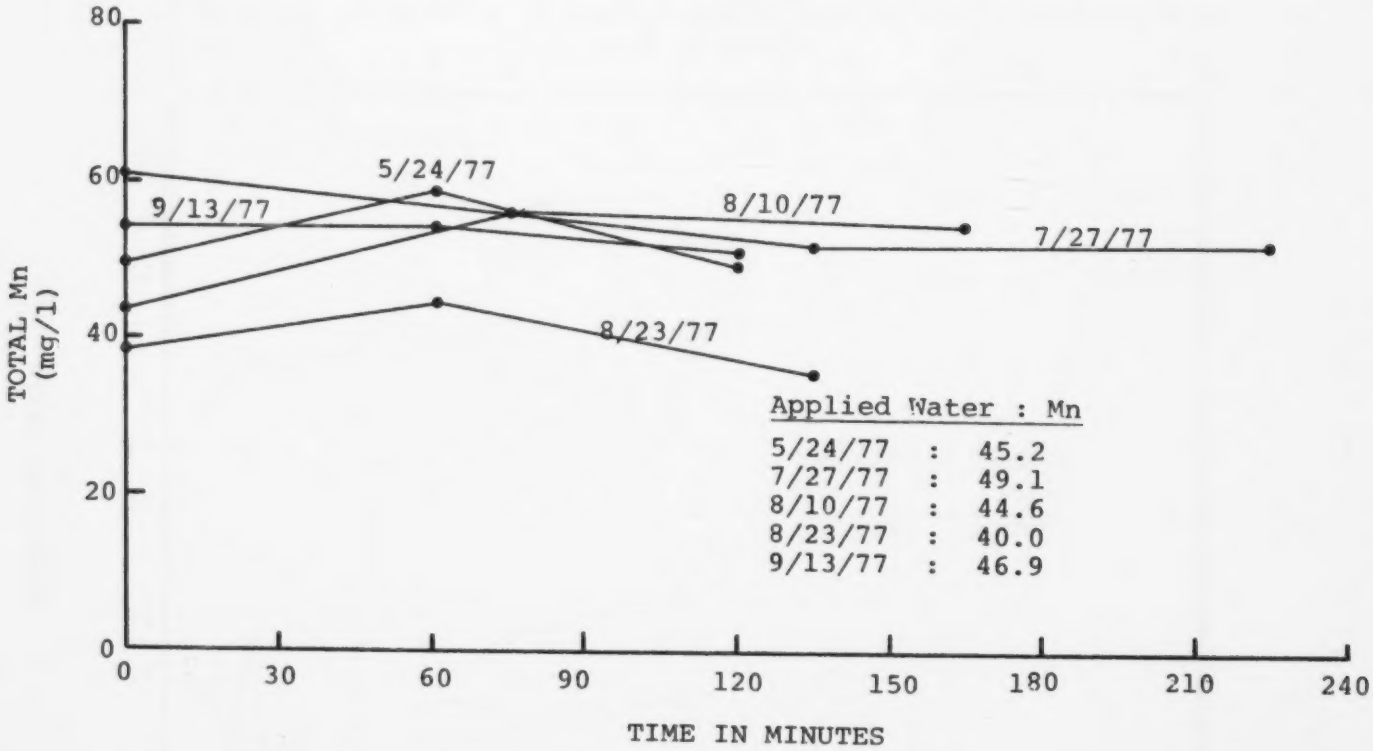

Figure 19. Analysis of discharge water from Plot 4, raw water, May-October 1977.

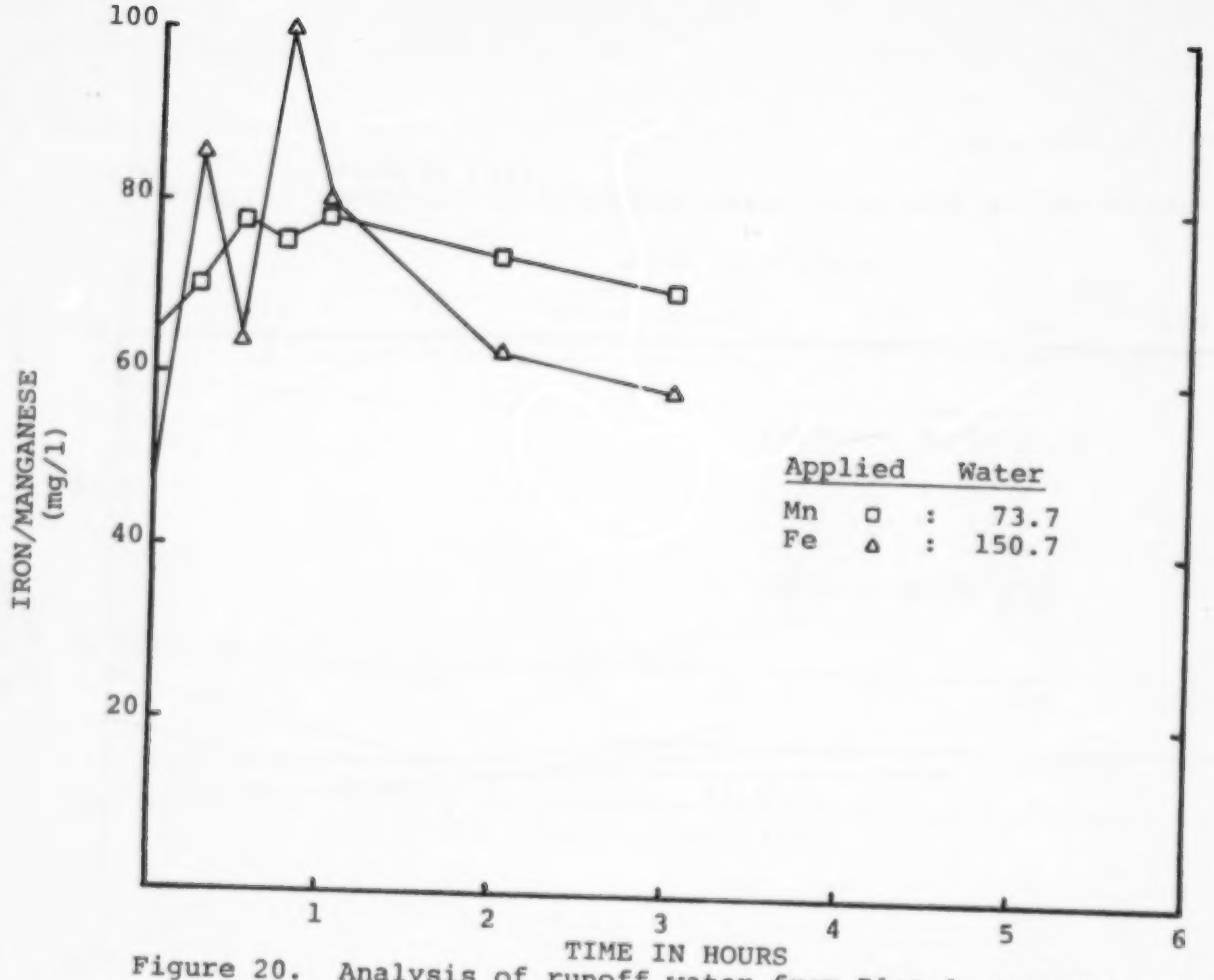

Figure 20. Analysis of runoff water from Plot 1, treated water with sludge, 5 October 1978.

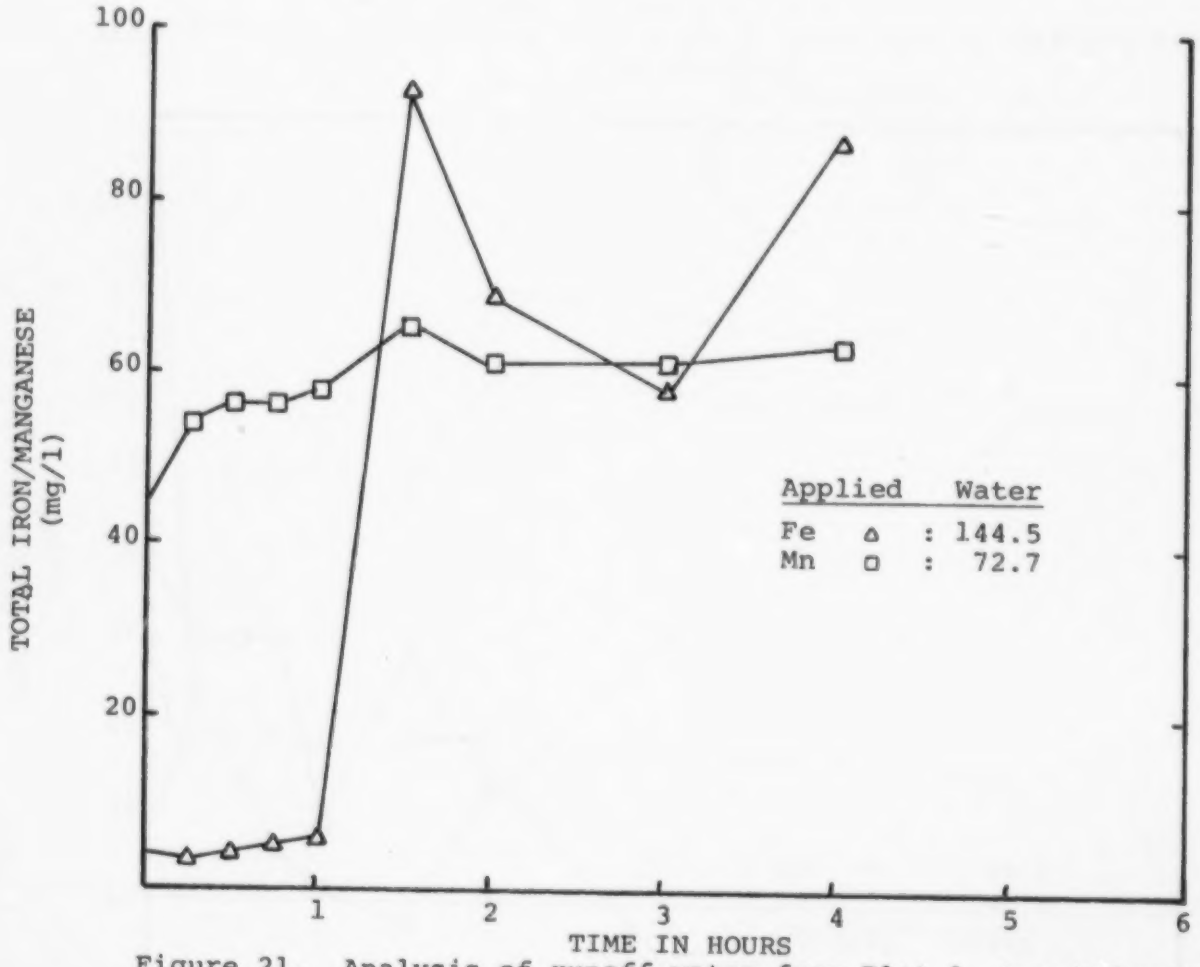

Figure 21. Analysis of runoff water from Plot 1, treated water with sludge, 6 October 1978.

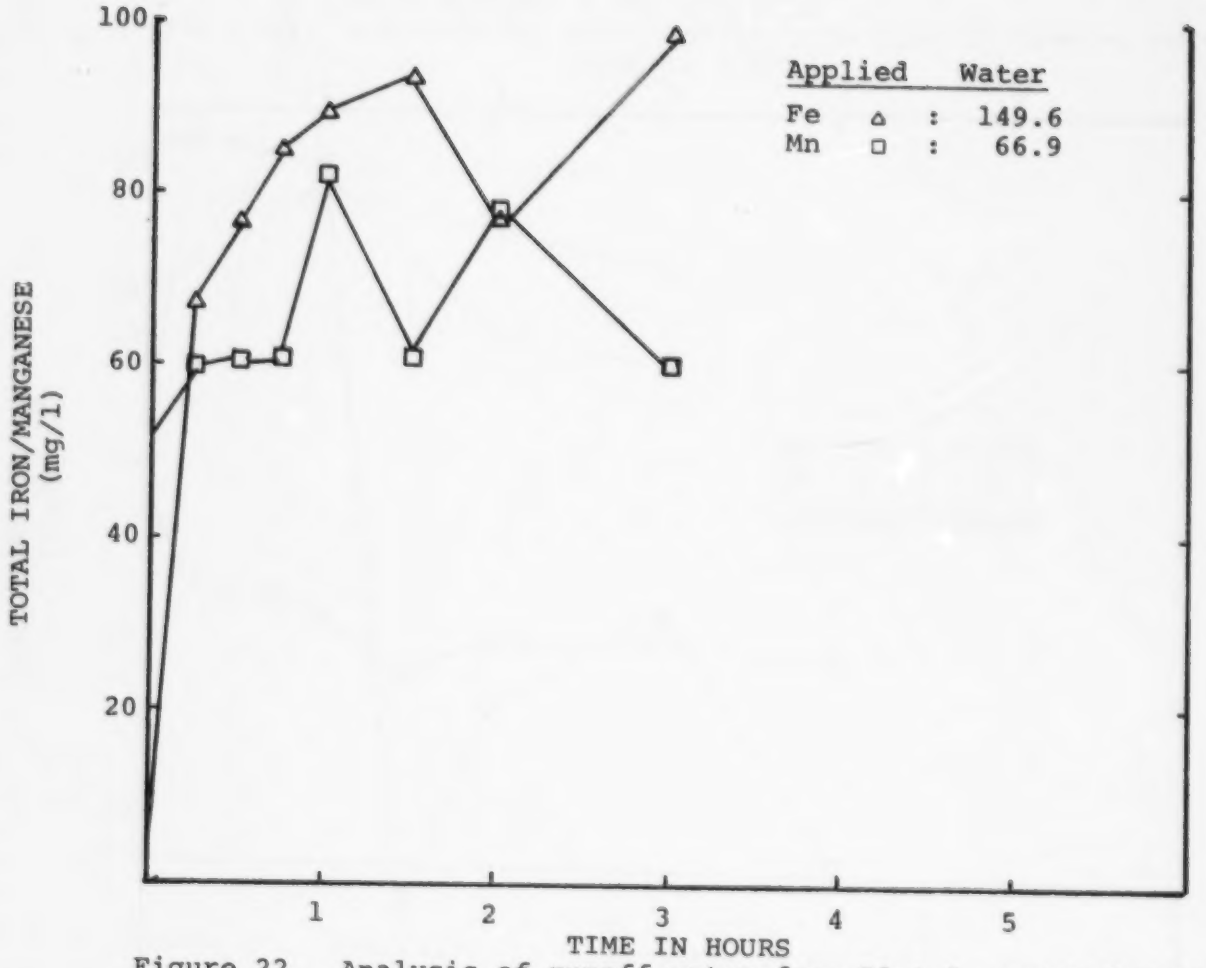

Figure 22. Analysis of runoff water from Plot 1, treated water with sludge, 17 October 1978.

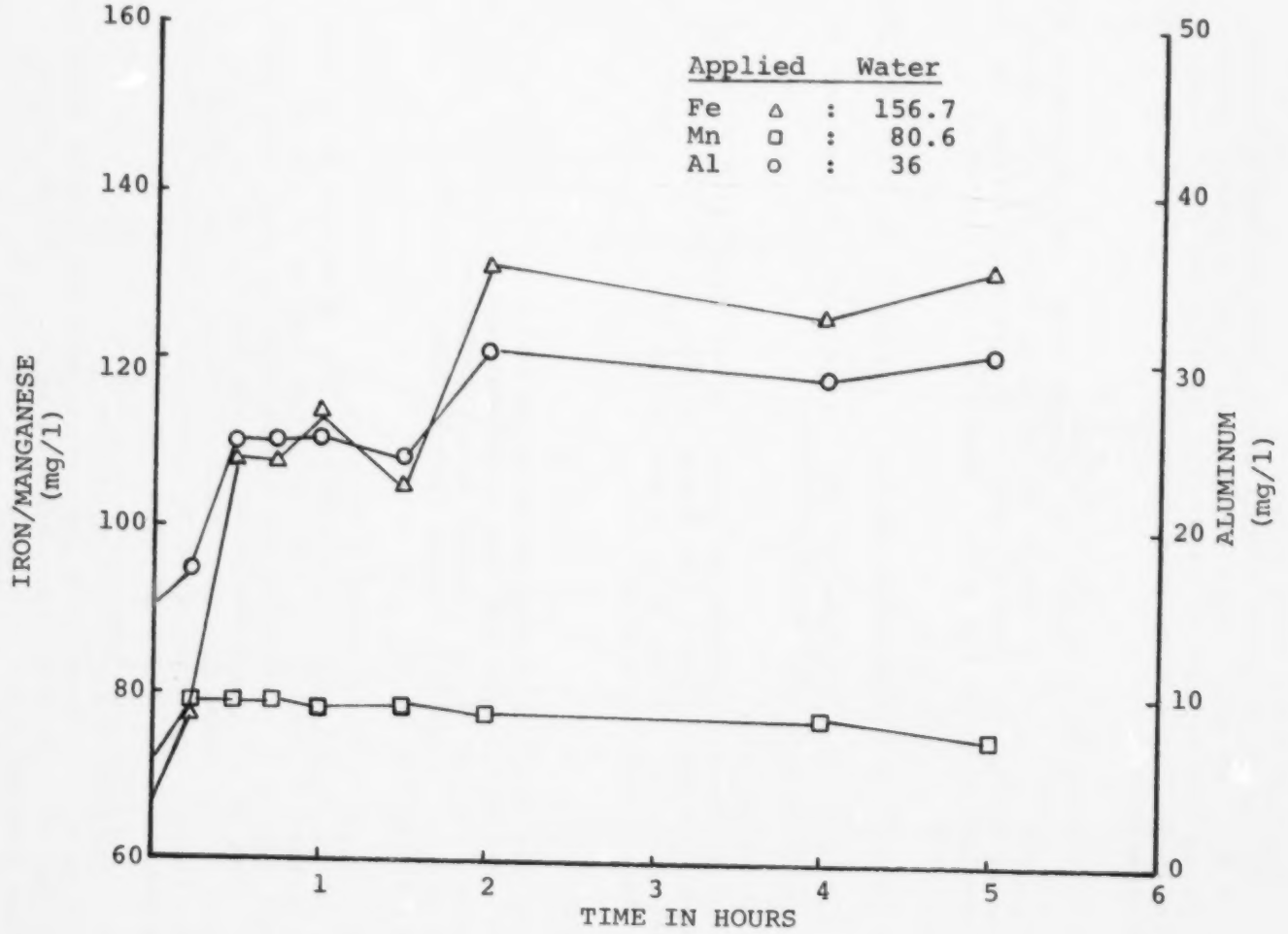

Figure 23. Analysis of runoff water from Plot 1, treated water with sludge, 25 October 1978.

of applied water (Figures 27, 28 and 29). TDS runoff values ranged from 4100 to 5300 mg/l; whereas, applied TDS values values ranged from 3750 to 4500 mg/l (Figures 27, 28 and 29).

Plot 1 - Treated Water With Sludge
Plot 1 produced irrigation runoff water that ranged between 4200-4800 mg/l of TDS. This runoff was significantly larger than applied TDS values of 3874-4338 mg/l (Figure 27). No appreciable difference existed between this plot and the other two treatments.

Plot 2 - Treated Water Without Sludge
Irrigation runoff from this plot ranged from 4100-5100 mg/l of TDS. The TDS of applied water varied from 3854 to 4507 mg/l. The treated water was approximately 400-500 mg/l higher in TDS after passing through the plot. There are two possible explanations:

1. Additional dissolved salts were picked up from the plot.

2. Evaporation of some of the irrigation water caused an increase in TDS concentration.

Plot 4 - Raw Water
This plot produced irrigation runoff water from 4300 to 5250 mg/l of TDS. The applied TDS loads ranged from 3754 to 4511 mg/l (Figure 29). As in plot 1 and 2 the TDS of the runoff was approximately 500 mg/l higher.

Aluminum

Aluminum was monitored periodically in order to determine the fate of this metal through the treatment and irrigation cycles. This metal proved to be a major metal component of the raw and runoff water. Aluminum values ranged from 2 to 120 mg/l in runoff irrigation water.

Plot 1 - Treated Water With Sludge
This plot produced the highest values for aluminum in irrigation runoff water (Figure 30). The aluminum values of runoff obtained for this plot were not appreciably higher than applied rates. The pH of the treated water was sufficiently high (above 6.0) to cause precipitation of this metal (Strumm and Morgan, 1970). However since no retention time was provided little removal of this parameter was noted.

Plot 2 - Treated Water Without Sludge
Irrigation runoff from this plot contained the lowest aluminum levels for all three plots. Applied water aluminum values were low (ranged 3.4 - 0.5 mg/l) as compared to a range of 10 - 30 mg/l applied to plots 1 and 4. The once through treatment by limestone and retention of 16 - 24 hours was usually

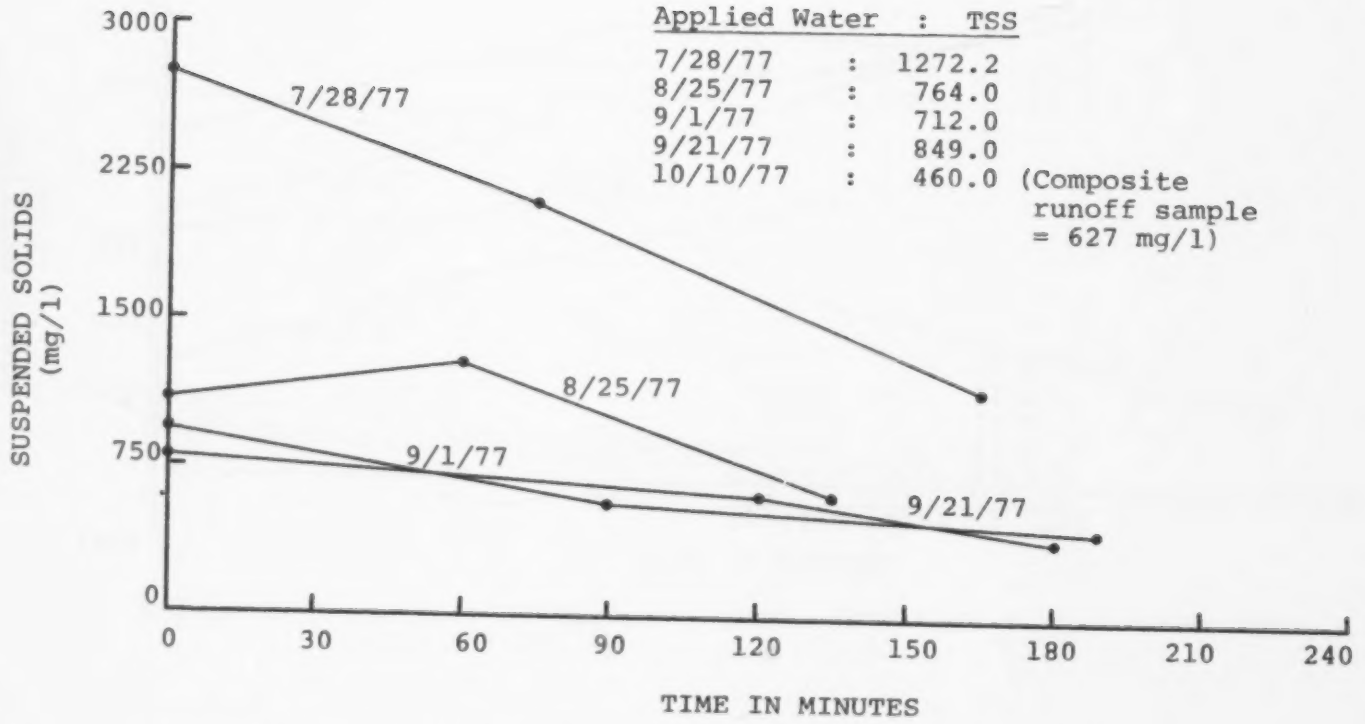

Figure 24. Analysis of discharge water from Plot 1, treated water with sludge, May-October 1977.

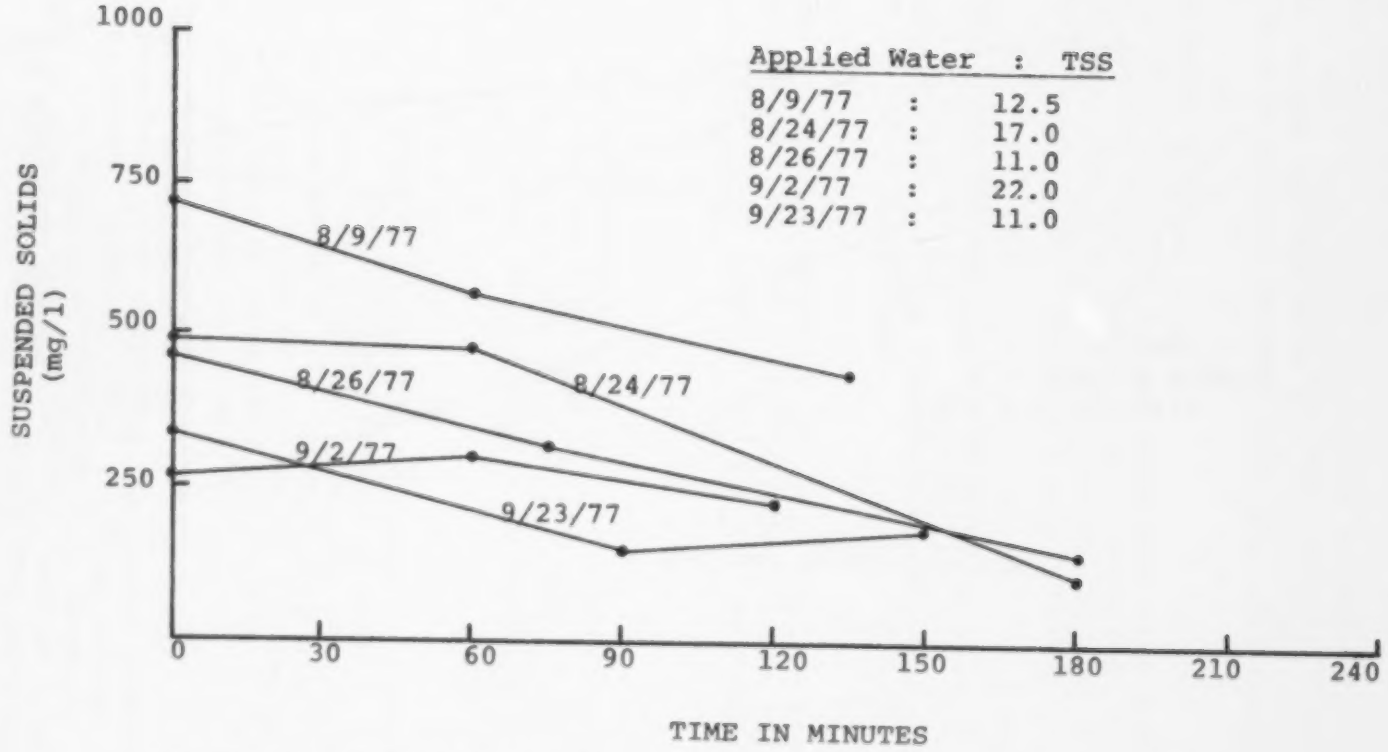

Figure 25. Analysis of discharge water from Plot 2, treated water without sludge, May-October 1977.

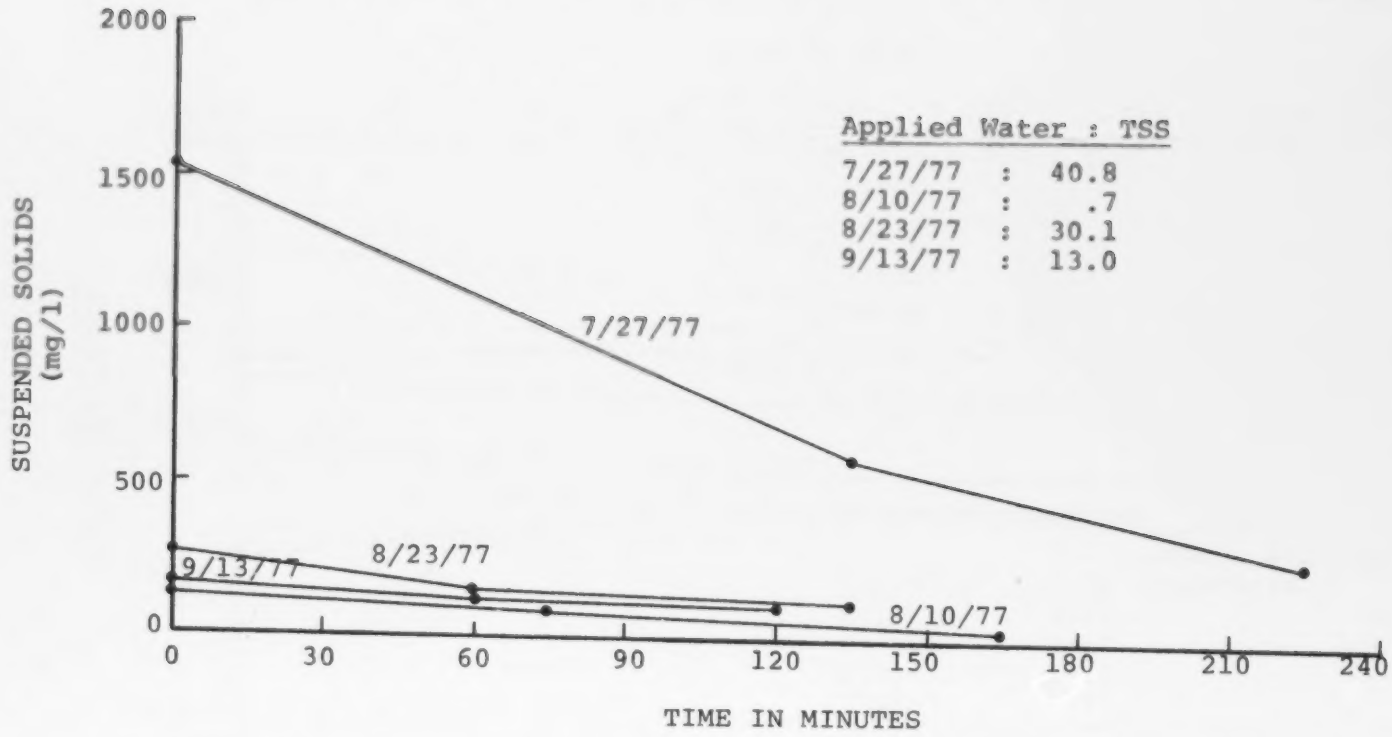

Figure 26. Analysis of discharge water from Plot 4, raw water, May-October 1977.

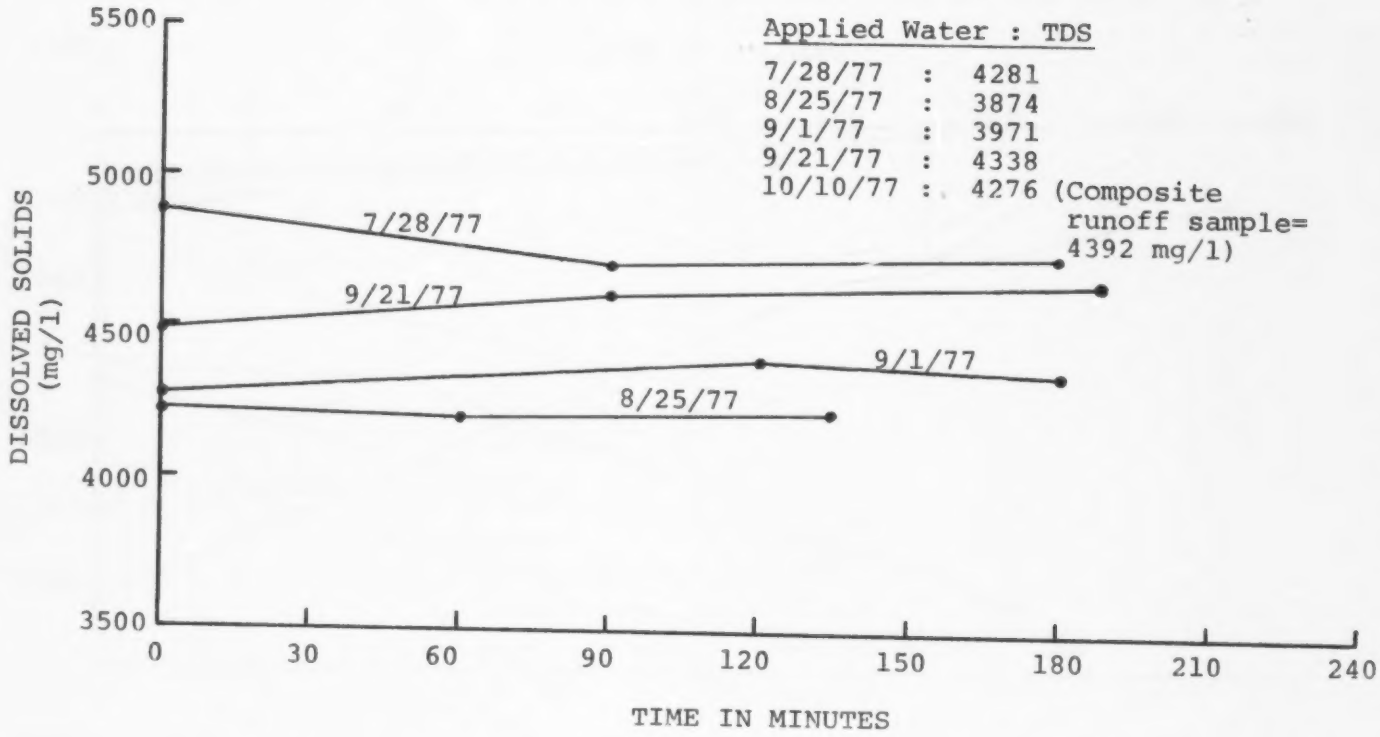

Figure 27. Analysis of discharge water from Plot 1, treated water with sludge, May-October 1977.

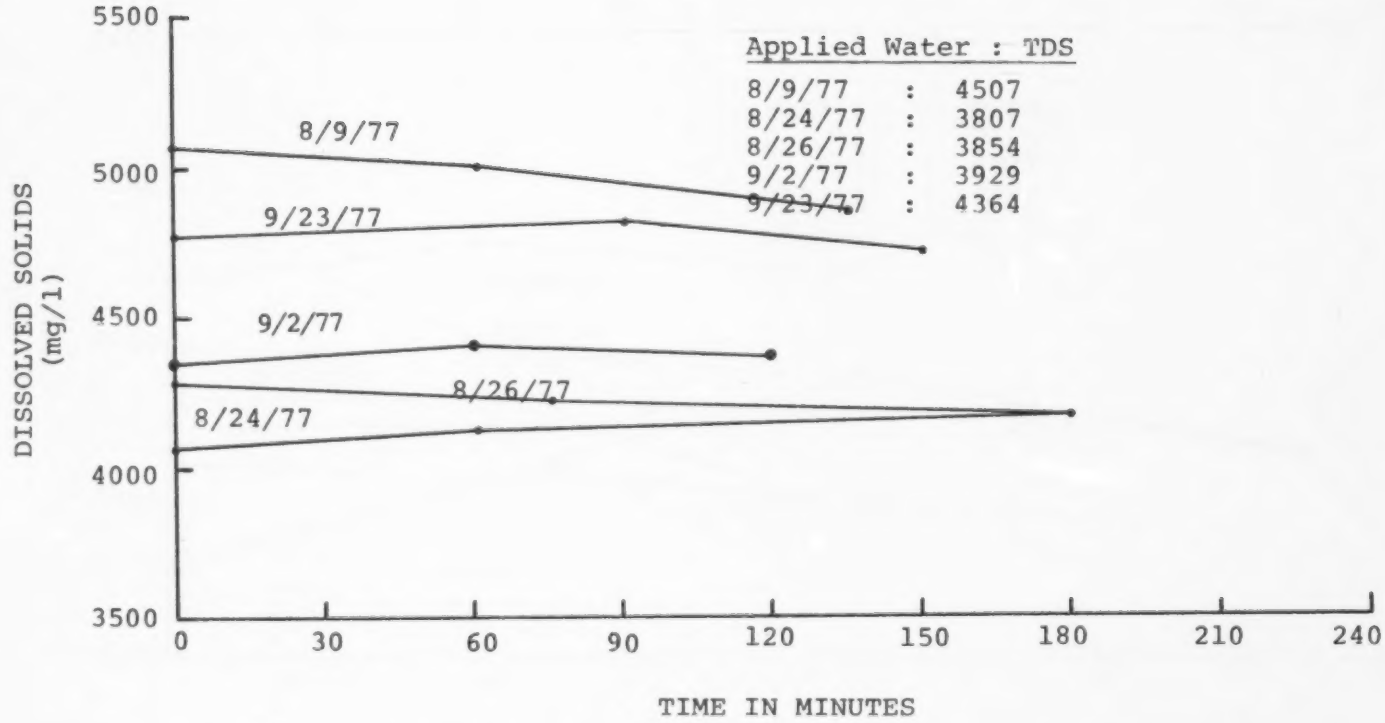

Figure 28. Analysis of discharge water from Plot 2, treated water without sludge, May-October 1977.

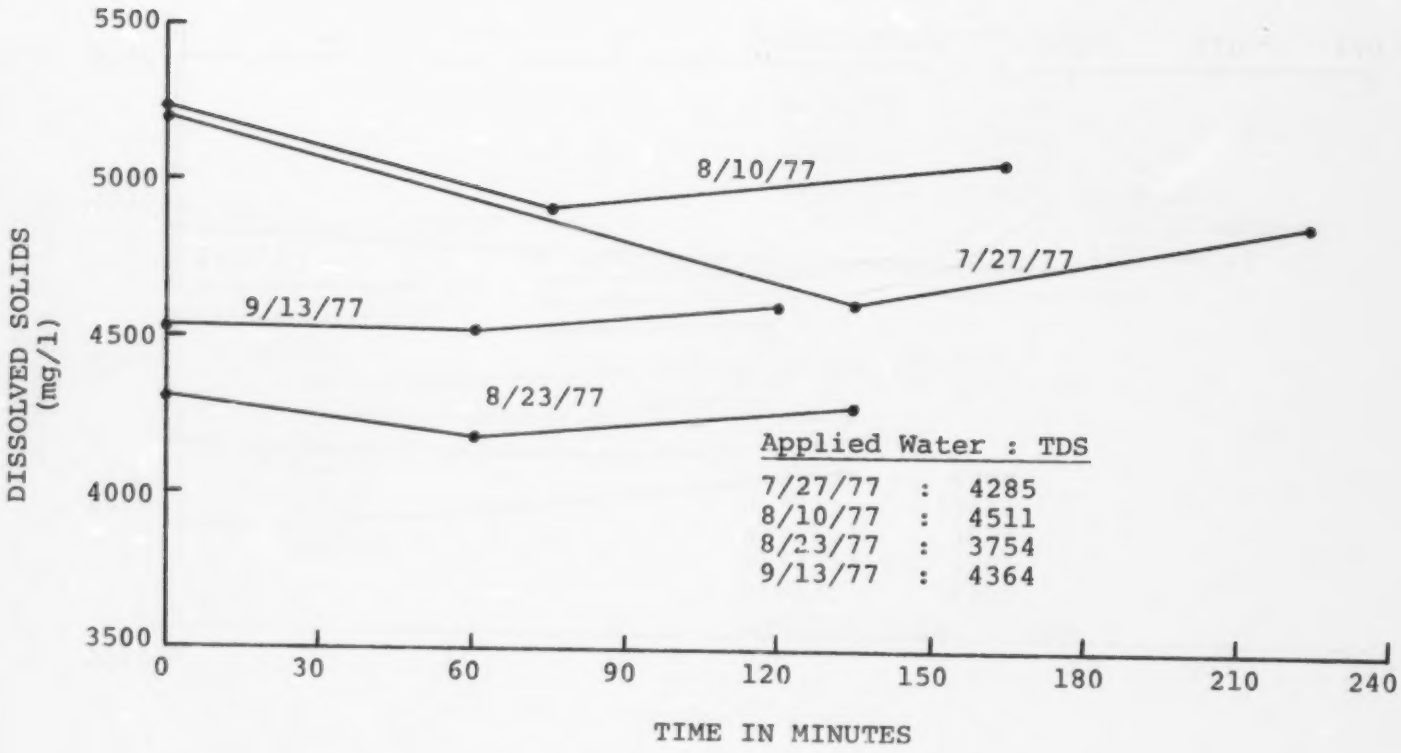

Figure 29. Analysis of discharge water from Plot 4, raw water, May-October 1977.

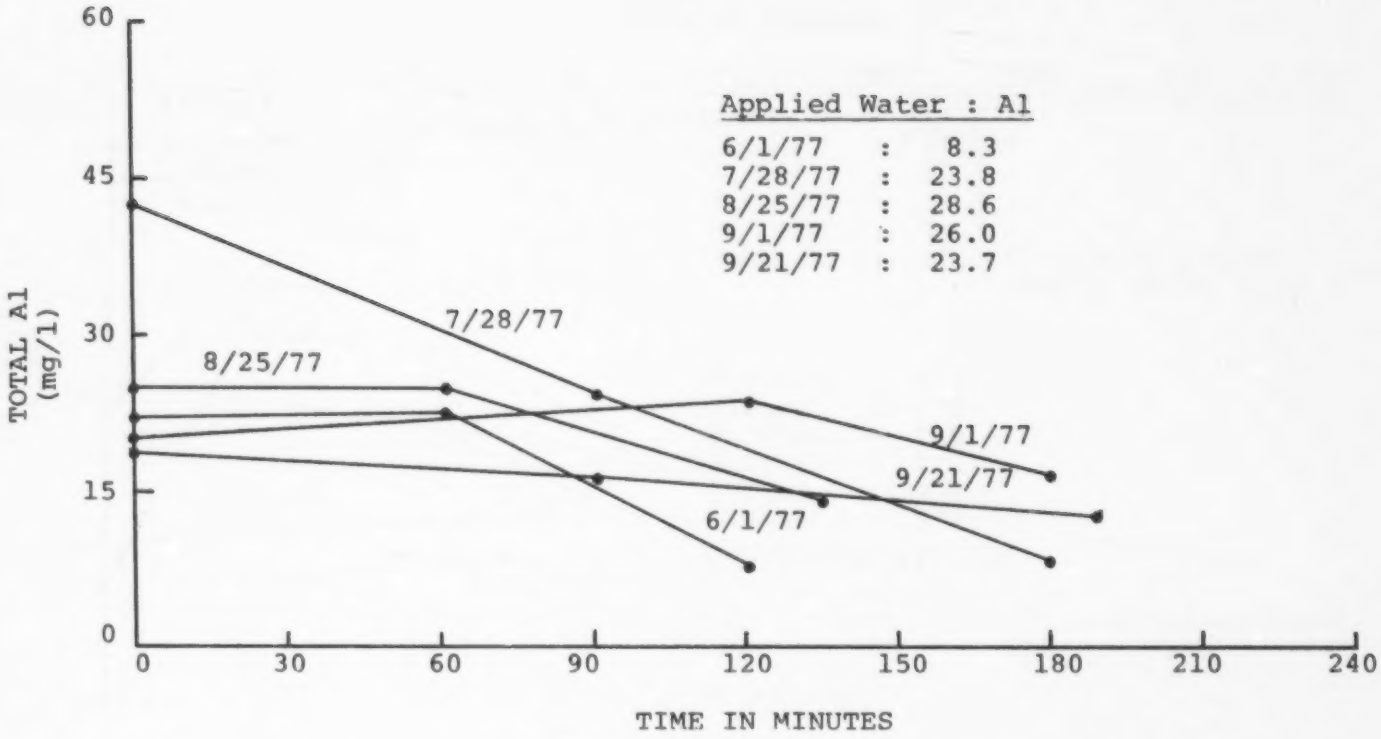

Figure 30. Analysis of discharge water from Plot 1, treated water with sludge, May-October 1977.

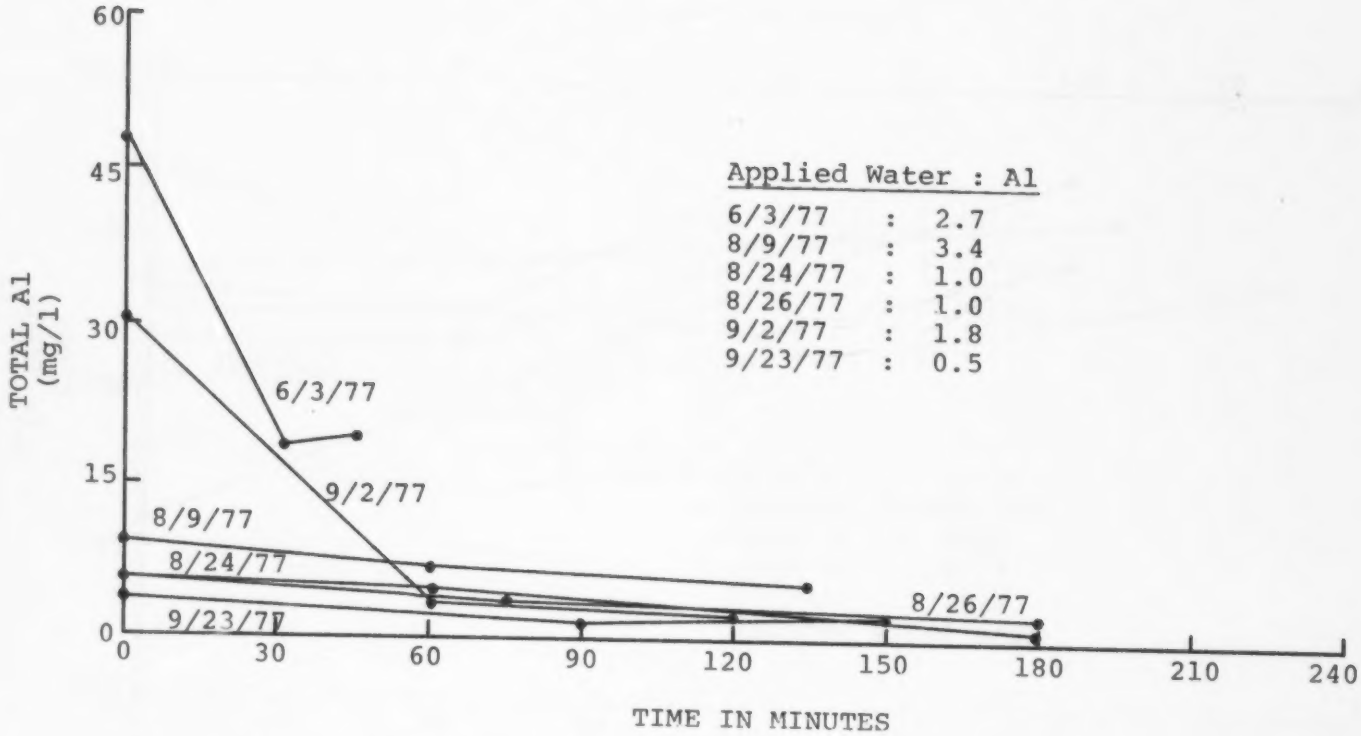

Figure 31. Analysis of discharge water from Plot 2, treated water without sludge, May-October 1977.

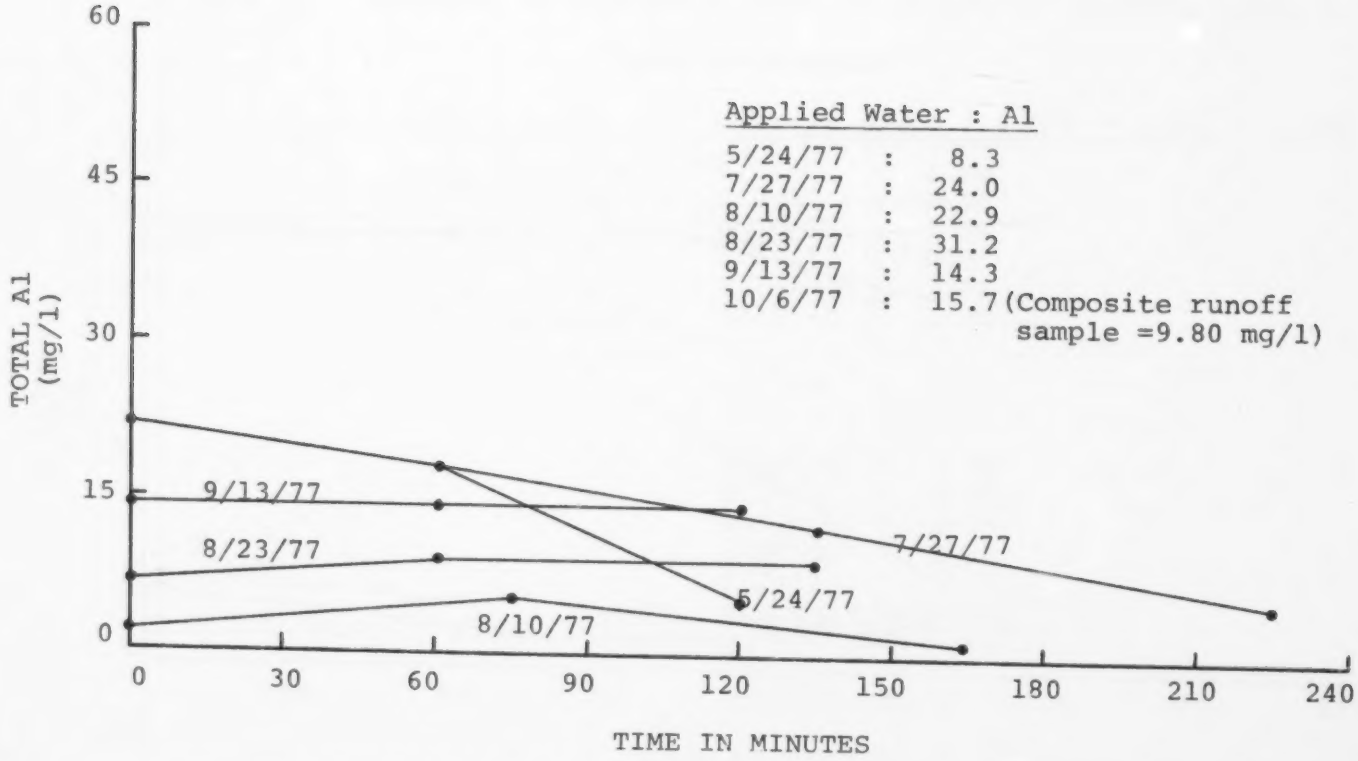

Figure 32. Analysis of discharge water from Plot 4, raw water, May-October 1977.

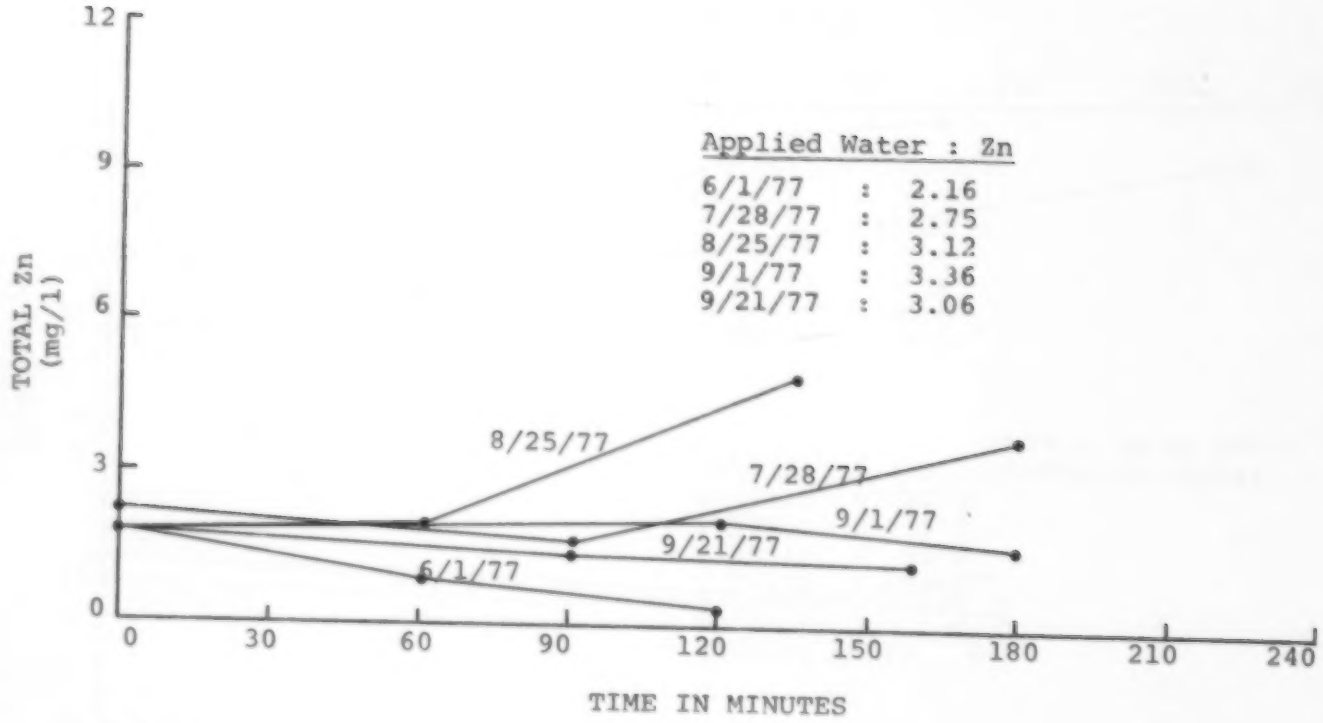

Figure 33. Analysis of discharge water from Plot 1, treated water with sludge, May-October 1977.

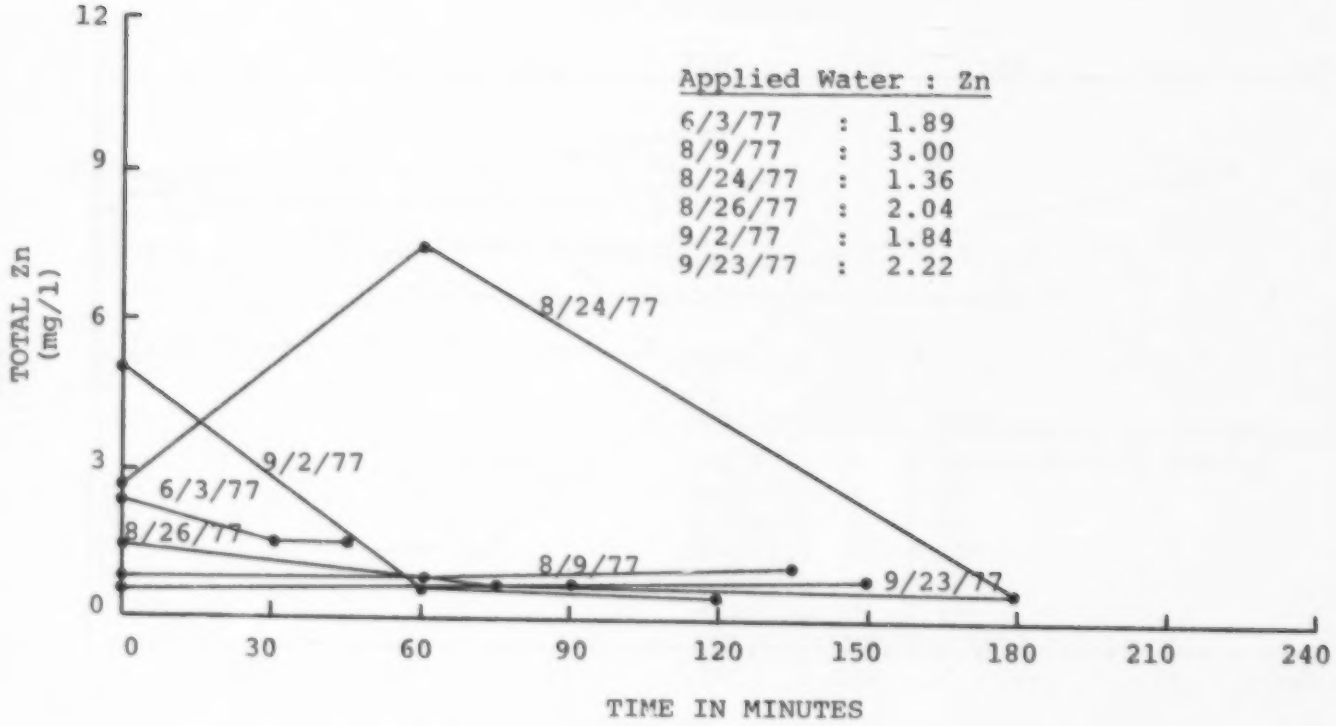

Figure 34. Analysis of discharge water from Plot 2, treated water without sludge, May-October 1977.

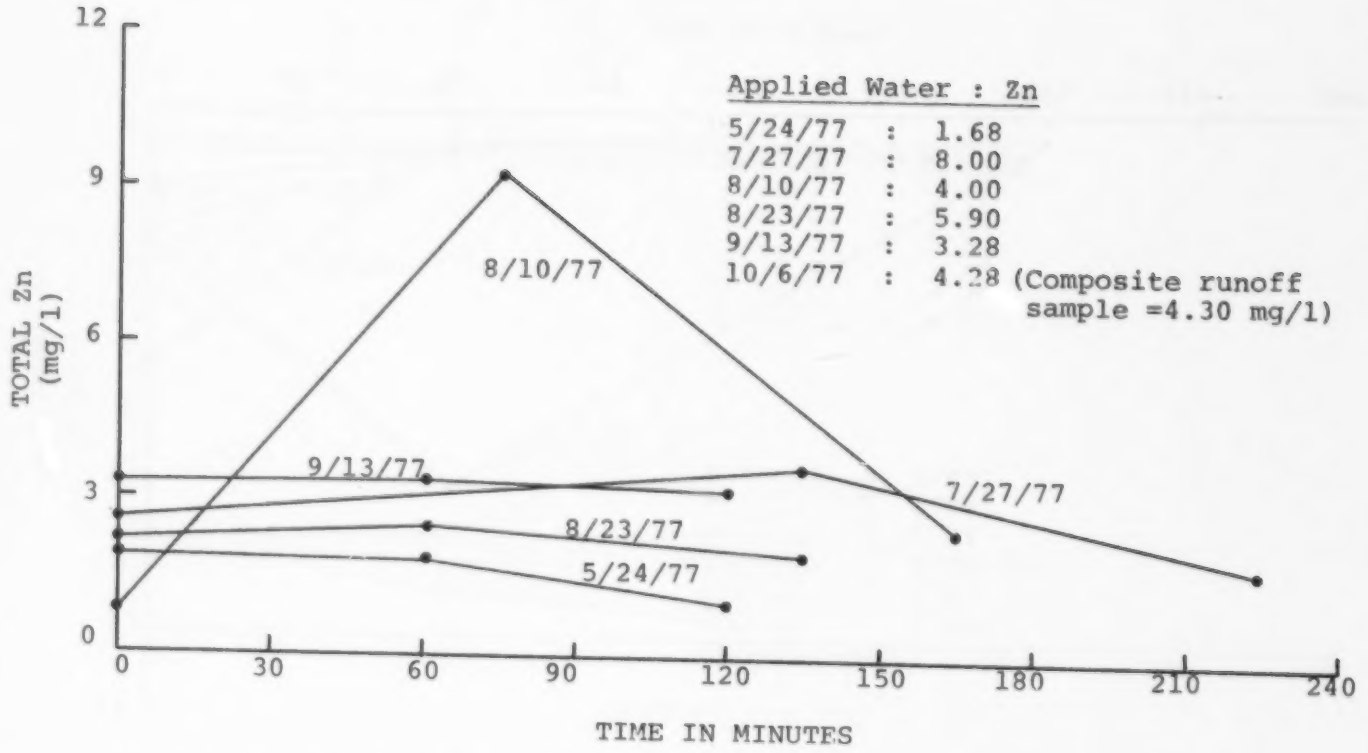

Figure 35. Analysis of discharge water from Plot 4, raw water, May-October 1977.

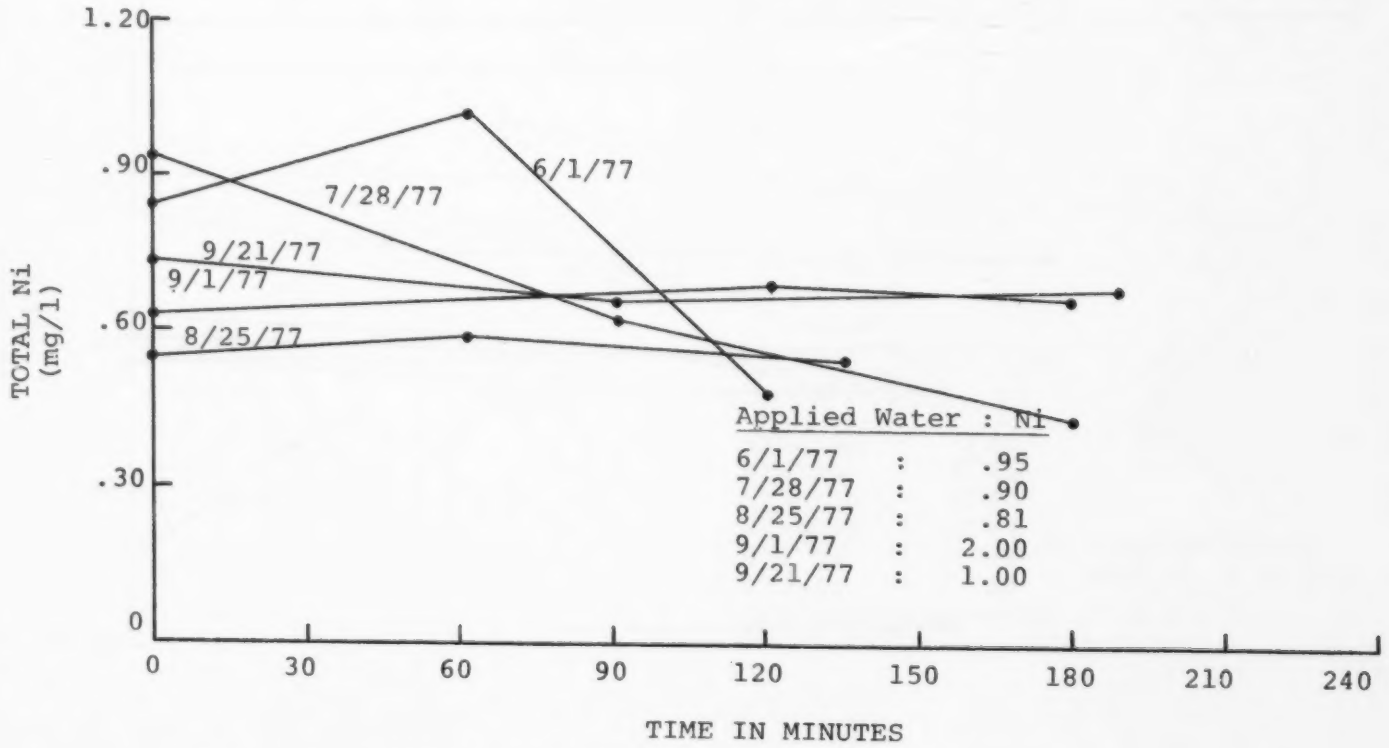

Figure 36. Analysis of discharge water from Plot 1, treated water with sludge, May-October 1977.

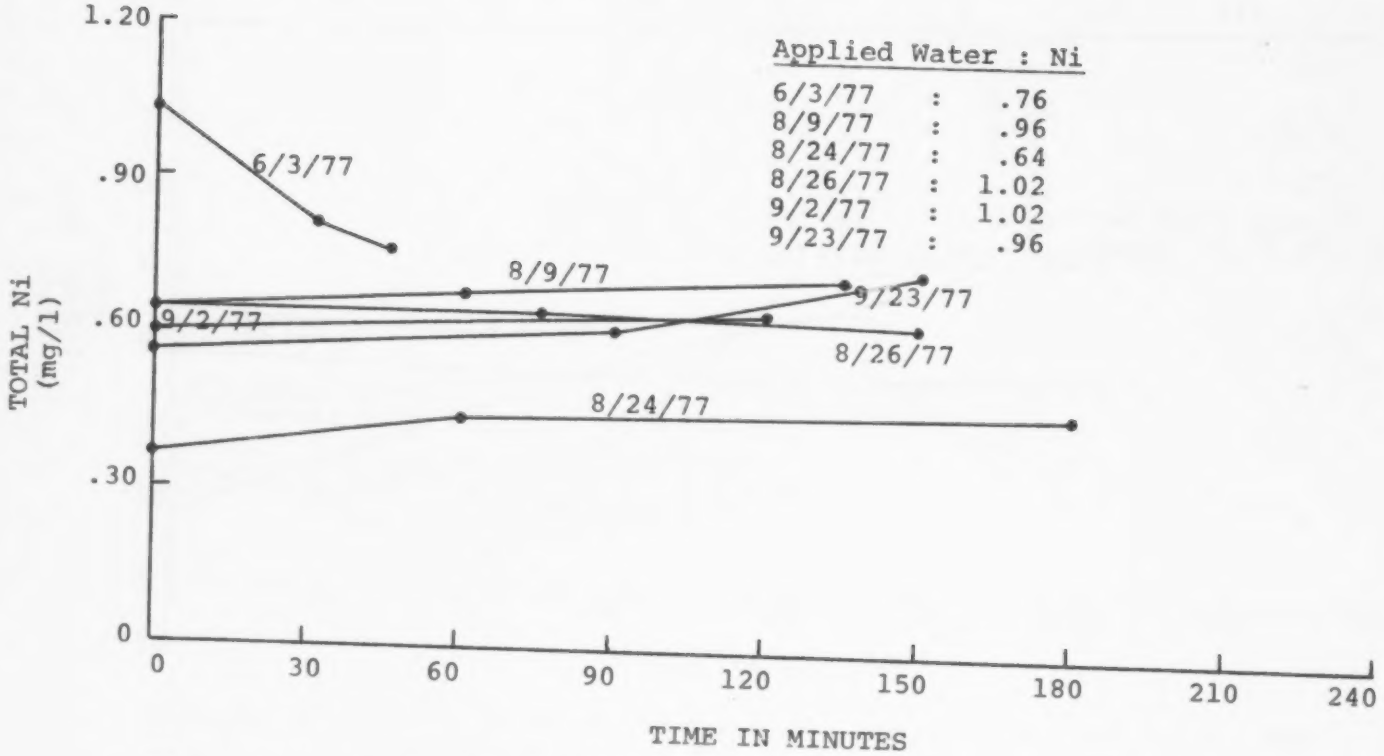

Figure 37. Analysis of discharge water from Plot 2, treated water without sludge, May-October 1977.

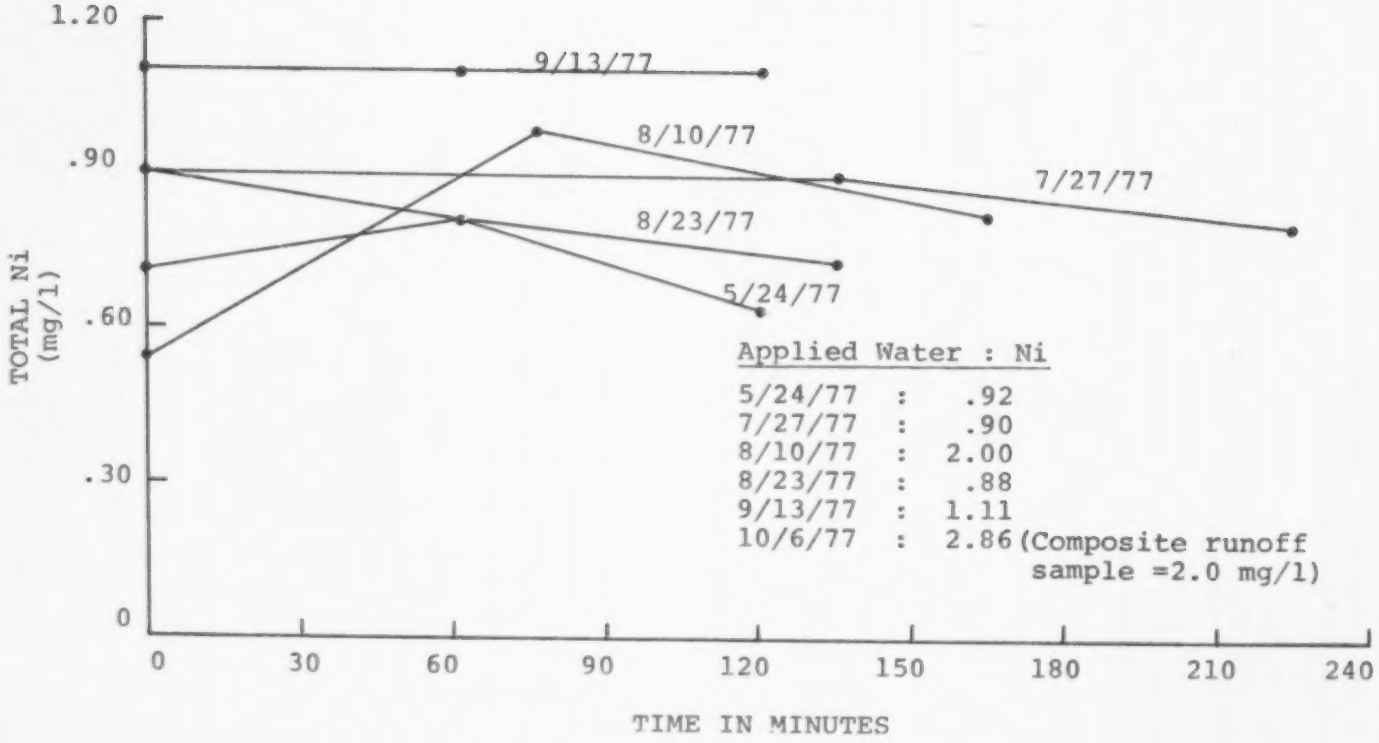

Figure 38. Analysis of discharge water from Plot 4, raw water, May-October 1977.

adequate to reduce aluminum to values of less than 2.5 mg/l. Aluminum will readily oxidize and precipitate out of solution at pH's of 5.2 or greater. The pH limit was always exceeded by the neutralization method employed.

Plot 4 - Raw Water
This plot produced irrigation runoff water which was lower in total aluminum than applied levels. This apparent retention of aluminum on the plot was perhaps associated with a coating of aluminum hydroxide on limestone surfaces or a possible chelate of aluminum with various organic compounds.

Zinc and Nickel

Zinc levels ranged from 1 to 9 mg/l in runoff irrigation water (Figures 33, 34, and 35). Zinc values appeared to be lowest in plot 2 runoff; hence there was significant removal of zinc by treatment with rock dust and 18 - 24 hour retention time.

Nickel data indicated that plot 2 produced irrigation runoff water of slightly lower nickel concentration than plots 1 or 4. Plot 4 produced the highest nickel values of 1.10 mg/l (Figures 36, 27 and 38). There was no apparent nickel trend to fluctuate in a specific manner with time from the start of irrigation.

VEGETATION

One objective of the project was to measure the effects of the various types of treatments (raw water, treated water with sludge and treated water without sludge) on the vegetation. Evaluation of vegetation response was in terms of harvest yields (Table 14) and percent cover (Table 15).

In addition to harvest yields, percent ground cover was used to compare vegetation among plots (Table 15). Percent ground cover (presence or absence of vegetation at designated intervals along a line transect) was also used as a criteria for evaluating vegetation response to various water treatments associated with irrigation. Table 15 indicates the percent ground cover values obtained for each plot (Figure 39).

Plot 1 - Treated Water With Sludge
This plot exhibited high harvest yields (3193 ka/ha) and 70 percent ground cover. This plot produced significantly greater harvest yields and percent ground cover than either the control or raw water treatment. However plot 1 produced slightly lower harvest yield and ground cover than treated water without sludge (Plot 2). Yet these differences between plots 1 and 2 were not significant.

TABLE 14. EFFECT OF IRRIGATION TREATMENT ON OVEN-DRIED HARVEST YIELDS

Plot	Treatment	kg/ha FA*	SCBG**	Average
1	Treated water with sludge	2764	3623***	3193
2	Treated water without sludge	3736	2765	3250
3	Control	475	1030	752
4	Raw water	3069	1841	2455

* FA = fescue/alfalfa.
** SCBG = sweet clover/bermuda grass.
*** Major invasion of fescue into sweet clover/bermuda grass portion of plot 1.

TABLE 15. PERCENT COVER OF PLOTS

Date	Method	Plot	percent cover FA*	SCBG**	Average
6/1979	Line transect	1	68	82	75.2
6/1979	Line transect	2	79	86	82.7
6/1979	Line transect	3	64	59	61.7
6/1979	Line transect	4	55	72	63.5
7/1978	Aerial photo	1	65	75	70.0
7/1978	Aerial photo	2	75	75	75.0
7/1978	Aerial photo	3	45	40	42.5
7/1978	Aerial photo	4	50	50	50.0
8/1978	Aerial photo	1	65	75	70.0
8/1978	Aerial photo	2	70	70	70.0
8/1978	Aerial photo	3	35	35	35.0
8/1978	Aerial photo	4	65	50	57.0

* FA = Kentucky-31 tall fescue and buffalo alfalfa.
** SCBG = Yellow blossum sweet clover and bermuda grass.

The sweet clover/bermuda grass (SCBG) side of the plot produced greater amounts of dry matter and ground cover than the fescue/alfalfa (FA) plot side. Although in all other plots, except the control, the fescue/alfalfa half out performed the sweet clover/bermuda grass combination. Part of the explanation could be with the large invasion of fescue into the SCBG side of this plot. The SCBG plot side was on the downslope of this plot.

In addition, the SCBG side of all plots had considerable invasion of volunteer plant species. Most noticeable was Goldenrod (Solidago sp.). It was found very prevalent on the SCBG plot side and appeared scarce on the FA plot side.

Bermuda grass populations diminished following the first growing season. It is not known whether the severe winters of 1977 and 1978 were solely responsible for its reduction or instead it experienced a gradual loss of stand vigor. This researcher noted that the bermuda grass stands were similarly affected in the surrounding areas in both spoil and non-spoil areas.

Plot 2 - Treated Water Without Sludge
This plot produced the highest harvest yields and percent cover of all plots. Even though these values were greater than those obtained for treated water with sludge, the difference was not significant. On the other hand, the harvest yield of plot 2 (3250 kg/ha) and the ground cover of 82 to 75 percent were significantly higher than the raw water treatment or the control plot. Goldenrod was extensively prevelant in the SCBG side of the plot.

Plot 3 - Control
This plot received normal reclamation practices of liming, disking, fertilizing and seeding as did all plots. The harvest yields of this plot were meager (752 kg/ha) and the ground cover was substandard as only 35-60 percent ground cover was achieved. (Tables 14 and 15, respectively). The yield of dried plant matter was approximately 25 percent of the plots irrigated with treated water and 31 percent of the yield obtained from the raw water plot.

Plot 4 - Raw Water
The raw water treatment produced significantly less harvest yield and ground cover than either plots 1 or 2. However the raw water plot did significantly out perform the control plot with respect to harvest yields and ground cover (Tables 14 and 15). The harvest yield of 2455 kg/ha is similar to yield data reported by Barnhisel et al, 1975 for phosphorus and tillage experiments in western Kentucky. This suggests there is an apparent benefit from irrigation of water on acid spoils even when the applied water is of low pH and high acidity (Table 13). There are several other possible explanations. Of which, accelerated leaching is plausible. Increased leaching has been

Plot 1 - Treated Water Plus Sludge

Plot 2 - Treated Water Without Sludge

Figure 39. Photographs showing the vegetation response to the different treatments, 1977.

Plot 3 - No Irrigation

Plot 4 - Raw Water Irrigation

Figure 39. (Continued).

established to improve vegetation response on poor spoil sites (Riley, 1973). Another logical possibility is that excess limestone in the spoil served to neutralize the water to a sufficient extent in order to be beneficial to the plant community. The limestone existed from the initial liming operation. This latter explanation is reinforced by water quality data which indicates a substantial improvement in pH and acidity from the applied water (Table 13; Figures 4 and 7). In many instances the water was applied at a pH of 3.6 and the resulting runoff water (a portion of which was available to the plants for growth) was above a pH of 6.0. It is unknown which one, or if a possible combination of explanations could be responsible for the observed results.

RUNOFF

Discharges from the irrigation plot varied with the intensity of irrigation. Peak runoff appeared to be from 230 to 285 liter/minute (60 to 75 GPM) depending upon application rate (455-625 liters/minute). Initial runoff commenced at from 40 to 70 minutes after the start of the irrigation cycle. The lower intensity irrigation rates produced longer lag phases between irrigation and runoff (Figure 40). The amount of surface runoff produced from the plot ranged from 26 to 33 percent of the total water volume applied. The amount of surface runoff was related to both intensity and duration of irrigation. At the cessation of irrigation, surface runoff diminished 50 to 60 percent of comparable time immediately before the shut down of the irrigation pump. The shape of the curve and time required to attain peak flows were found related to irrigation intensity. The peak runoff values were approximately 50 percent of the applied rate. The irrigation rates were not varied under sufficient seasonal differences and soil moistures to give a prediction; but it is known that those variables will effect the amount and duration of runoff (Linsley, 1975).

RAINFALL RUNOFF

Water samples representing surface runoff from each plot were collected during normal precipitation events. The runoff from all four plots were similar in most water quality parameters. Analyses of samples taken 20 January and 28 July 1979 are shown in Table 16.

Natural precipitation from all plots met mine drainage effluent limits established by the U.S. EPA and the Office of Surface Mining. Alkaline pH readings were obtained from all plots. Acidity values were zero on all samples. Alkalinity values ranged from 28 to 80 mg/l. The highest alkalinity was recorded from plot 1 (treated water plus sludge), which received by-products of water treatment. This higher alkalinity value is

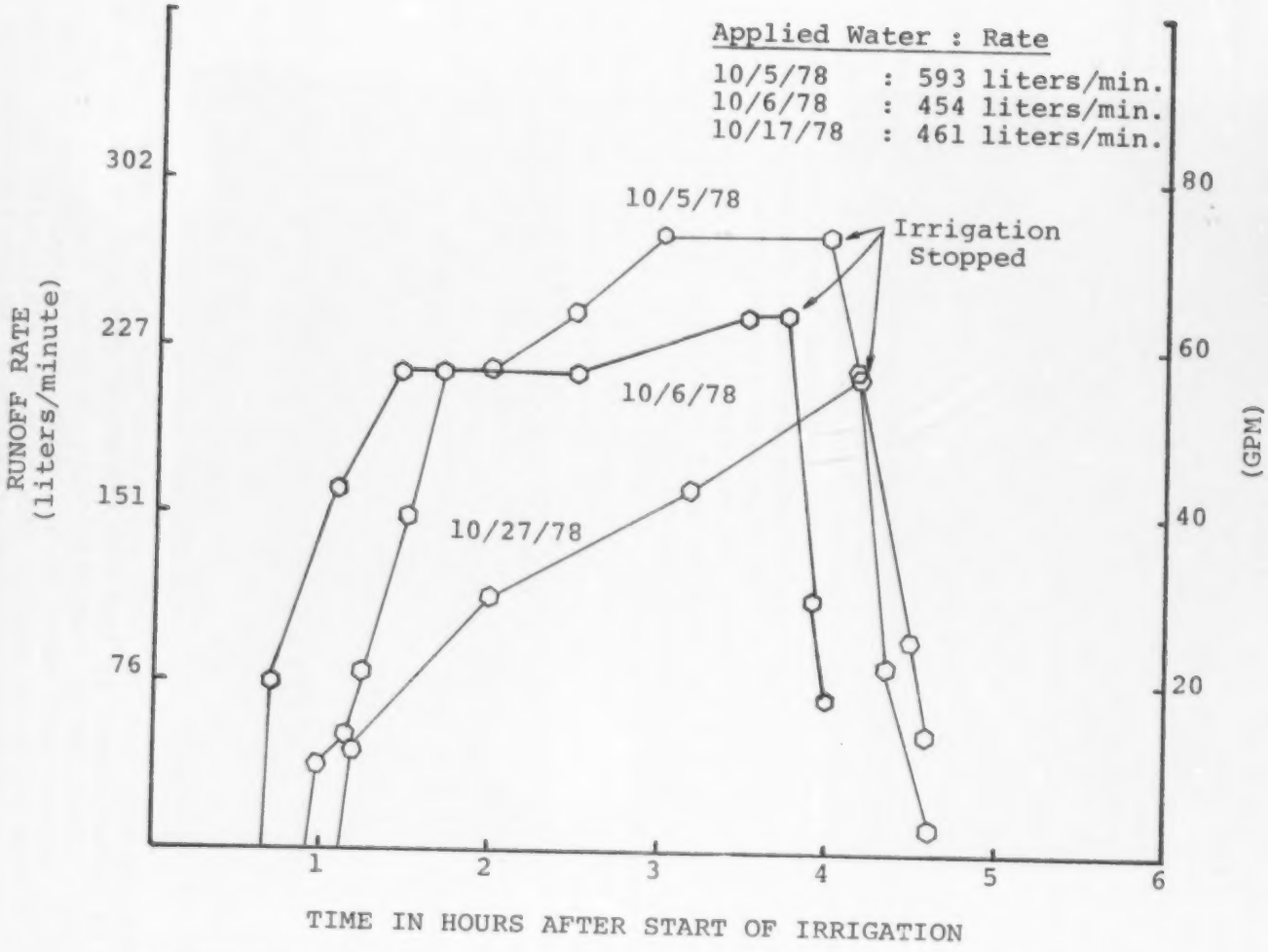

Figure 40. Hydrograph showing runoff volumes during irrigation of plot 1, 1978.

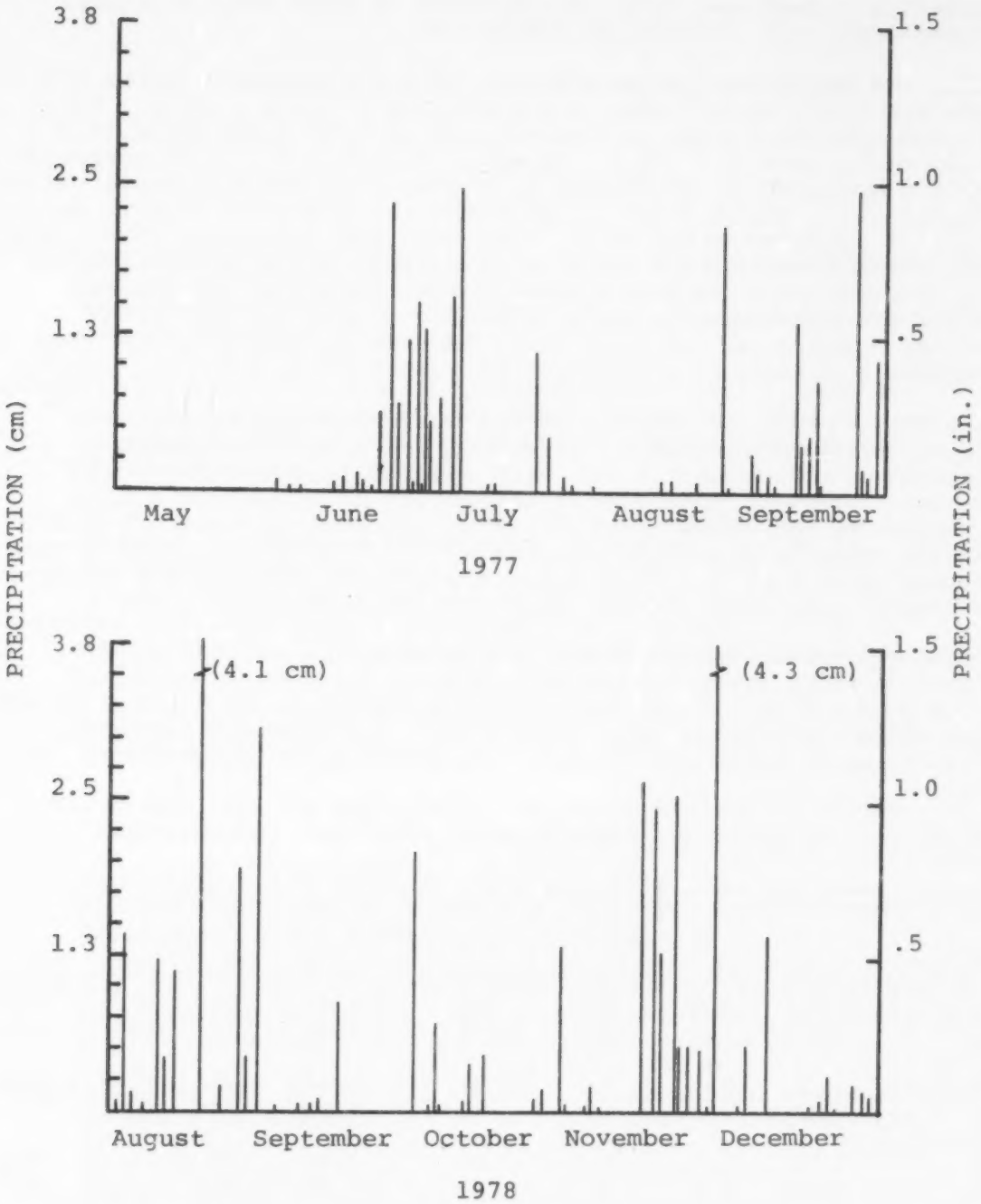

Figure 41. Precipitation patterns at Vogue-EPA irrigation site, Muhlenberg County, 1977-1978.

possibly a response from the addition of fine mesh rock dust (limestone) via irrigation (Table 16).

Iron and manganese concentrations were considerably below the average limit established for discharge of mine waters. Plot 1 produced the lowest concentrations of both components (0.8 - 1.05 mg/l; iron and .06 - .15 mg/l; manganese). High suspended solids appeared to be linked to higher iron and manganese values (Table 16). Plots 1 and 2 (with the exception of 28 July on plot 2) produced water with lower iron and manganese than 3 and 4. These lower values could be a reflection of the irrigation of treated water on these plots. The irrigation of treated water produced greater densities of ground cover and plant matter (Tables 14 and 15). This vegetation protected the ground surface and reduced the amount of suspended solids.

All plots produced water with low suspended solids (10.0 - 46 mg/l). No discernible difference was apparent between irrigated and control plots with regards to suspended solid loads. However, upon visual inspection of suspended solids trapped on the glass fiber filters, it appeared that organic matter made up a greater portion of TSS from plots 1 and 2 than either plot 3 or 4. This could explain why smaller TSS loads produced relatively higher metal values from plots 3 and 4.

Total dissolved solids (TDS) ranged from 450 to 1210 mg/l. Significantly lower values were present in samples obtained from plots 1 and 2 that received treated water as opposed to the raw water or control plot (Table 16). Perhaps the irrigation with treated water did enhance the leaching of total dissolved solids.

TABLE 16. ANALYSES OF STORM RUNOFF

			mg/l					
Plot*	Date	pH	Acidity	Alkalinity	Iron	Mn	TSS	TDS
1	1/20	7.5	0	80	0.80	.06	10	580
1	7/28	7.5	0	40	1.05	.15	15	450
2	1/20	7.5	0	72	1.46	.25	46	758
2	7/28	7.6	0	33	2.69	.24	43	591
3	1/20	7.5	0	58	1.82	.60	26	1090
3	7/28	7.5	0	28	1.49	.48	12	700
4	1/20	7.5	0	64	1.75	.74	18	1210
4	7/28	7.5	0	28	3.47	.90	59	1155

* 1 - treated water plus sludge, 2 - treated water without sludge, 3 - no irrigation, 4 - raw water.

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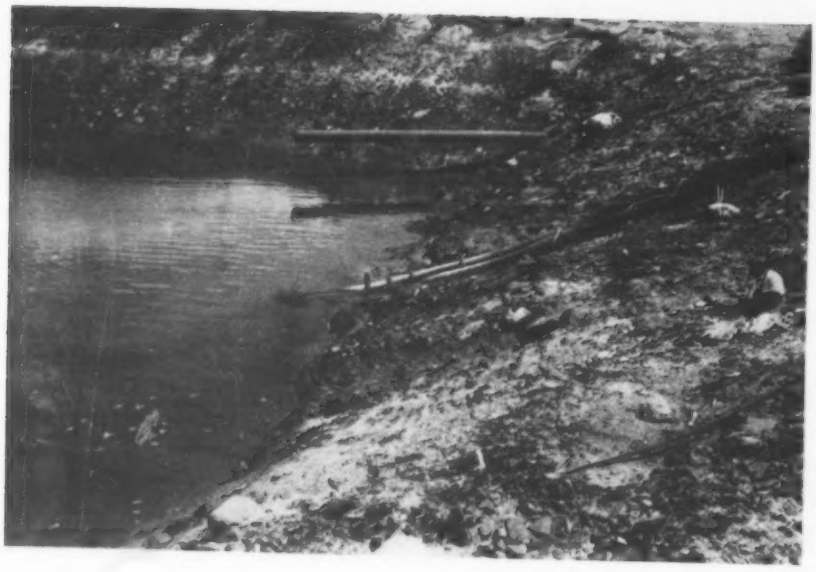
APPENDIX

TABLE 17. SEIVE ANALYSIS OF ROCK DUST, FREDONIA QUARRIES

Screen size	Rock dust (limestone), percent passing
70	98
100	95
200	75
325	65

TABLE 18. MANUFACTURER'S CHEMICAL ANALYSIS OF ROCK DUST (LIMESTONE)

Parameter	As percent of rock dust
$CaCO_3$	97.6
$MgCO_3$	1.5
SiO_2	0.7
Aluminum and iron oxides	0.2



Raw Water Lagoon and Steel Water Line Feeding Irrigation Pump

Electric Limer Utilized in Project

Figure 42. Photographs showing raw lagoon and limer used in project.

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High Pressure Irrigation System Under Operation

Monitoring Station for Recording and Sampling Runoff

Figure 43. Photograph showing monitoring station and irrigation.

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16. ABSTRACT
This study provided a field demonstration of an earlier feasibility study. Treated acid mine drainage was utilized to augment revegetation on graded spoil areas. Acid mine drainage was treated utilizing limestone (rock dust) and the resulatant water was spray irrigated under high pressure onto the plots. Three treatment and a control were used to evaluate the effects of the irrigation on the vegetation and resulting surface runoff. The three treatments applied via irrigation were raw acidic water, treated water with sludge and treated water without sludge. All three treatments enhanced vegetation response in varying degrees when compared to the control plot. Irrigation of treated water with sludge deposited some of the sludge (treatment by-products, unreacted limestone and ferric hydroxide) onto the plots. When irrigation was applied at a rate of 2.5 cm/4 hours, approximately 30 percent of the water was recovered as surface runoff. No detrimental water quality impact was noted by the deposition of treatment sludge onto the plots. Runoff from natural precipitation events produced runoff water of similar quality to control areas. This report was submitted in fulfillment of Project 14010 HNS by the Kentucky Department for Natural Resources and Environmental Protection under the sponsorship of the U.S. Environmental Protection Agency. Work was completed as of December 1979.

17. KEY WORDS AND DOCUMENT ANALYSIS

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